

January 1973

## A Water Resource Management Model, Upper Jordan River Drainage, Utah

Bi-Huei Wang

James I. Felix

Rick L. Gold

Craig T. Jones

J. Paul Riley

Follow this and additional works at: [https://digitalcommons.usu.edu/water\\_rep](https://digitalcommons.usu.edu/water_rep)



Part of the [Civil and Environmental Engineering Commons](#), and the [Water Resource Management Commons](#)

---

### Recommended Citation

Wang, Bi-Huei; Felix, James I.; Gold, Rick L.; Jones, Craig T.; and Riley, J. Paul, "A Water Resource Management Model, Upper Jordan River Drainage, Utah" (1973). *Reports*. Paper 23.

[https://digitalcommons.usu.edu/water\\_rep/23](https://digitalcommons.usu.edu/water_rep/23)

This Report is brought to you for free and open access by the Utah Water Research Laboratory at DigitalCommons@USU. It has been accepted for inclusion in Reports by an authorized administrator of DigitalCommons@USU. For more information, please contact [digitalcommons@usu.edu](mailto:digitalcommons@usu.edu).



**A WATER RESOURCE MANAGEMENT MODEL,  
UPPER JORDAN RIVER DRAINAGE, UTAH**

**by**

**Bi-Huei Wang  
James I. Felix  
Rick L. Gold  
Craig T. Jones  
J. Paul Riley**

**The work reported by this project completion report was supported primarily with funds provided by the United States Department of the Interior, U.S. Bureau of Reclamation, under Project Number WG91, Investigation Period June 22, 1970, to October 31, 1972.**

**Utah Water Research Laboratory  
College of Engineering  
Utah State University  
Logan, Utah 84322**

**April 1973**

**PRWG91-1**



## ABSTRACT

As demands upon available water supplies increase within a river basin, there is an accompanying increase in the need to assess the downstream consequences resulting from changes at specific locations within the hydrologic system. This problem is approached in this study by digital computer simulation of the hydrologic system. Modeling concepts are based upon basic relationships which describe the various hydrologic processes. Within a hydrologic system these relationships are linked by the continuity-of-mass principle which requires a mass balance at all points. Spatial resolution is achieved by considering the modeled area as a series of subbasins. The time increment adopted for the model is one month, so that time varying quantities are expressed in terms of mean monthly values. The model is general in nature and is applied to a particular hydrologic system through a programmed verification procedure whereby model coefficients are evaluated for the particular system.

In this study the model was applied to the Provo River basin of northern Utah, with emphases being placed upon water rights and operation of storage reservoirs within the system, including Utah Lake. The simulation model consists of three specific parts, namely: (1) parameter optimization; (2) river basin management; and (3) Utah Lake operation. The parameter optimization submodel identifies the model parameters for each subbasin through application of a parameter optimization technique. The river basin management submodel, using the optimized parameters, simulates the hydrologic response of the system to various water resources management alternatives. The Utah Lake operation submodel is linked with the river basin management submodel to comprise a combined Utah Lake operations model. Some comparisons between observed and computed outflow hydrographs at various points within the Provo River basin are shown. The utility of the model for predicting the effects of various possible water resource management alternatives is demonstrated.

Wang, Bi-Huei; Felix, James I; Gold, Rick L.; Jones, Craig T.; and Riley, J. Paul.

A WATER RESOURCE MANAGEMENT MODEL, UPPER JORDAN RIVER DRAINAGE, UTAH  
Research Project Technical Completion Report to the U.S. Bureau of Reclamation, Department of the Interior, April, 1973, Washington, D.C.

**KEYWORDS**—hydrologic models\*/hydrologic simulation\*/computer simulation\*/simulation\*/groundwater/watershed studies\*/snowmelt/evapotranspiration/deep percolation/water yields/hydrologic relationships/hydrologic research\*/hydrology/hydrologic data/evaporation\*/water salinity management\*/water resource planning and management\*

## ACKNOWLEDGMENTS

This publication represents the final report of a project which was supported primarily with funds provided by the U.S. Bureau of Reclamation of the United States Department of the Interior. The project involved a cooperative study between personnel from Utah State University and the U.S. Bureau of Reclamation, Central Utah Project Office, Provo, Utah, whereby a computer simulation model was developed for managing water resource systems. The model, although general in nature, is applied to the Provo River basin in Central Utah. The study involved rather detailed considerations of both surface and groundwater hydrology, and has required that other constraints be included, such as water rights and reservoir operating rules for multi-purpose development.

For this reason, counterpart teams of professionals were established at both the University and at the Provo District Office of the Bureau of Reclamation. Throughout the study there was a high degree of interchange through numerous meetings and discussions both at the University and at the Bureau offices in Provo. The teams from the University and the USBR have worked closely in developing and testing the model, and since then jointly have conducted several management studies involving water resource use and development in the Provo River basin, and the relationship of this resource use to the Central Utah Project being planned by the USBR. Personnel of the Bureau involved in the study are now thoroughly acquainted with the model and its development procedure, and are capable of applying it to various kinds of management studies in the future. This study has served to demonstrate that close cooperation between researchers and users, and the rapid "feedback" which this cooperation promotes, can lead to a highly effective application of research results.

The authors express gratitude to all who contributed to the success of this study. Particularly, special thanks are extended to Mr. Palmer DeLong, Project Manager, Central Utah Project, U.S. Bureau of Reclamation. The USBR supplied most of the financial support for this study, and in addition, Mr. DeLong and his staff provided valuable suggestions and direction throughout the entire project. In this respect, special acknowledgement is due to Mr. L. Gayle Moore, Chief of the Water Resources Branch, and to Mr. C. Roe Allman and Mr. Michael D. Staver, all of whom are engineers with the Central Utah Project Office, USBR, and who made substantial contributions during all phases of the study.

Bi-Huei Wang  
James I. Felix  
Rick L. Gold  
Craig T. Jones  
J. Paul Riley

## TABLE OF CONTENTS

Chapter	Page
I INTRODUCTION . . . . .	1
II DESCRIPTION OF THE STUDY AREA . . . . .	3
Location . . . . .	3
Climate . . . . .	3
Precipitation . . . . .	3
Temperature . . . . .	3
Land Use . . . . .	3
Drainage System . . . . .	3
Reservoirs and Streamflow Regulations . . . . .	3
Future Outlook . . . . .	5
III MATHEMATICAL MODELS . . . . .	7
General Considerations . . . . .	7
Model Development . . . . .	7
Time and Spatial Resolutions . . . . .	7
Hydrologic Balance . . . . .	7
Model Boundaries . . . . .	7
Model Components . . . . .	9
Precipitation . . . . .	9
Snowmelt . . . . .	9
Temperature . . . . .	9
Gaged Surface Inflow . . . . .	10
Ungaged Surface Inflow . . . . .	10
Groundwater Inflow . . . . .	10
Irrigation Diversions . . . . .	10
Municipal and Industrial Diversions . . . . .	11
Surface Return Flows . . . . .	11
Available Soil Moisture . . . . .	12
Evapotranspiration . . . . .	13
Deep Percolation . . . . .	14
Net Groundwater Recharge . . . . .	14
Groundwater Outflows . . . . .	15
Surface Outflow . . . . .	15
Total Outflow . . . . .	15

## TABLE OF CONTENTS (CONTINUED)

IV	COMPUTER IMPLEMENTATION . . . . .	17
	The Parameter Optimization Submodel . . . . .	17
	Basic Considerations . . . . .	17
	Objective Function . . . . .	17
	Implementation . . . . .	18
	Calibration of the Model . . . . .	20
	Testing of Calibration Results . . . . .	20
	The River Basin Management Submodel . . . . .	21
	Important Management Principles . . . . .	22
	Application . . . . .	26
	The Combined Utah Lake Operation Model . . . . .	26
	Lake Evaporation . . . . .	28
	Water Quality . . . . .	29
V	SUMMARY AND CONCLUSIONS . . . . .	31
	REFERENCES CITED . . . . .	32
	APPENDIX A: PARAMETER OPTIMIZATION MODEL . . . . .	33
	APPENDIX B: DATA PROGRAM . . . . .	51
	APPENDIX C: RIVER BASIN MANAGEMENT MODEL . . . . .	57
	APPENDIX D: COMBINED UTAH LAKE OPERATION MODEL . . . . .	79
	APPENDIX E: EVAPORATION FROM UTAH LAKE . . . . .	97

## LIST OF FIGURES

Figure	Page
2.1 Location of the Upper Jordan Drainage area . . . . .	4
2.2 Hydrologic measuring stations in the Upper Jordan Drainage area . . . . .	6
3.1 A simplified diagram of the hydrologic balance . . . . .	8
3.2 Modeled agricultural area within the subbasin . . . . .	8
3.3 Crop growth stage coefficient curve for dry beans . . . . .	13
4.1 Division of the Upper Jordan River basin for parameter optimization . . . . .	20
4.2 Division of the Upper Jordan River basin for management . . . . .	21
4.3 Computed and observed monthly streamflow from Francis Subbasin, 1950-1953 . . .	23
4.4 Computed and observed monthly streamflow from Area 2-3 Subbasin, 1950-1953 . . .	23
4.5 Computed and observed monthly streamflow from Area 4, 5, 6 Subbasin, 1950-1953 . .	24
4.6 A two reservoir system illustrating the manner in which the desired storage and desired streamflow criteria are implemented . . . . .	25
4.7 Lake and pan evaporation relationship, Utah Lake . . . . .	28
C-1 Reservoir surface area-storage capacity relationships . . . . .	64
E-1 Atmospheric radiation factor, $\beta$ (see Raphael, 1962) . . . . .	100
E-2a The comparison of simulated and observed lake storage, Utah Lake . . . . .	101
E-2b The comparison of simulated and observed lake storage, Utah Lake . . . . .	101
E-3 The comparison of simulated and observed water temperature, Utah Lake . . . . .	102





## LIST OF TABLES

Table	Page
2.1 Climatological characteristics of the Upper Jordan Drainage area (Huntzinger, 1971) . . . . .	5
2.2 Hydrologic measuring stations in the Upper Jordan Drainage area . . . . .	5
4.1 Parameter optimization sample output . . . . .	19
4.2 Results of parameter optimization . . . . .	22
4.3 Development alternatives for the Provo River Basin . . . . .	27
4.4 Total dissolved solids content, in ppm, of the various inflows to Utah Lake . . . . .	29
A-1 Definition of variables and parameters . . . . .	37
A-2 Definition of variables and parameters . . . . .	37
C-1 Definition of variable . . . . .	59
C-2 Definition of parameters . . . . .	59
C-3 Definition of simulated quantities . . . . .	60
C-4 Definition of model indicators . . . . .	60
D-1 Determination of spillrate into Goshen Bay . . . . .	83
E-1 Values of $(\Delta/\gamma)_0$ at 1,000 mbar, temperature T°C . . . . .	100



## CHAPTER I

### INTRODUCTION

This project was initiated in June 1970 with the signing of a cooperative agreement between the United States Bureau of Reclamation and the Utah Water Research Laboratory at Utah State University to develop a hydrologic simulation model for the Upper Jordan River drainage. The main objective of the study, as outlined in the original agreement between the two agencies, was to develop and verify a hydrologic computer model for the study area which is capable of determining the following:

1. Various water yields and outflows of the system under different operation criteria.
2. The capacity of the proposed Jordanelle Reservoir under various operation rules.
3. The water quality of Utah Lake as affected by various methods of satisfying demands.
4. The influence of different water management alternatives on the groundwater flow in the Utah Valley, including the variation of piezometric pressure.

Due to the lack of data for sophisticated groundwater analysis and the recognition of the importance of water right constraints on the system, the original agreement was modified in April 1972 to delete the analysis of variation in groundwater piezometric elevation and to substitute a consideration of important water right constraints imposed on the system.

To accomplish the objectives, a hybrid computer model first was developed for the Provo River Basin. Under this initial step the capability of the proposed hydrologic simulation model was tested and improved. This model subsequently was programmed on a digital computer for use by the Bureau of Reclamation, and expanded to include the entire Upper Jordan River drainage, with emphasis being placed upon the operation of Utah Lake.

The simulation model discussed in this report consists of three specific parts, each of which was developed independently, and is capable of functioning as a separate entity. However, when combined into a single model, each of the three separate models becomes a component or submodel of the whole, and is referred to as such throughout this report. The three components, or

submodels, perform the following specific functions or operations: (1) parameter optimization; (2) river basin management; and (3) Utah Lake operation. The parameter optimization submodel identifies the model parameters for each subbasin of interest through application of a parameter optimization technique. In this way, the simulation model is calibrated for each subbasin in the study area. The river basin management submodel, using the optimized parameters, simulates the hydrologic responses of the system to various water resources management alternatives. Represented by the model are rates of flow at different locations along the stream of interest, evapotranspiration and return flows from agricultural lands, soil moisture variations, reservoir storages, groundwater effluent flows, and other important processes in the hydrologic system. Through the operation of the model, reservoirs may be sized on the basis of different water management alternatives subject to various water right constraints.

The Utah Lake operation model was developed by the Central Utah Project Office of the Bureau of Reclamation to facilitate a study of the effects of the Central Utah Project on the hydrology of the lake, and particularly to evaluate the effects of diking within the boundaries of the present lake. When this model is linked with the river basin management model, the two become components or submodels of the so-called combined Utah Lake operations model. A water quality component was also incorporated into the combined model to enable the simulation of the variation of total dissolved solids in Utah Lake as a function of different water management schemes.

In this report, emphasis is placed upon the construction and application of the simulation model rather than upon the numerical values of the simulated results. Chapter II includes a brief description of the study area and the background behind the study, while Chapter III describes the mathematical equations used to describe the important hydrologic processes in the system. The computer version of the simulation model together with a discussion of the application of the model to the study area, are presented in Chapter IV. Chapter V discusses the results of the research and suggests the direction for further study.



## CHAPTER II

### DESCRIPTION OF THE STUDY AREA

#### Location

The Upper Jordan River drainage, covering an area of approximately 3,000 square miles, is located in the central part of the State of Utah, as shown in Figure 2.1. The area is part of the drainage system of the Great Salt Lake, which in turn is a part of the Great Basin.

#### Climate

The climate of the Upper Jordan River drainage may be described as temperate and semi-arid. Relatively low precipitation, low humidity, and high evaporation characterize the area. The summers are usually mild and the winters are cold, particularly in the higher elevations. The climatological characteristics of the area are summarized in Table 2.1 (Huntzinger, 1971).

#### Precipitation

Generally, the precipitation in the area decreases in a westerly direction from the Wasatch Mountains. In the lower valleys surrounding Utah Lake, the average annual precipitation varies from 12 to 16 inches. On the high peaks of the Wasatch Mountains, the average annual precipitation is more than 30 inches. The mountain valleys receive from 15 to 20 inches of precipitation annually.

#### Temperature

The mean annual temperatures on the valley floors surrounding Utah Lake range from 40 to 50 degrees Fahrenheit, while in the higher valleys of the Wasatch Mountains, corresponding temperatures are between 35 and 45 degrees Fahrenheit. A good summary of the temperature variation with respect to space and time within the study area is given in Hyatt et al. (1969). The locations of temperature and precipitation stations within and adjoining the Upper Jordan River drainage are shown in Figure 2.2, and the name of each station is listed in Table 2.2.

#### Land Use

Agriculture is the largest user of land within the Upper Jordan River drainage. There are approximately 220,000 acres of agricultural land in the area. Of this

acreage, more than 160,000 acres are irrigated. Alfalfa, pasture, grain, corn, sugar beets, and orchards are representative irrigated crops, with the largest amount of irrigated land being used for alfalfa and pasture.

In addition, some land within the basin is occupied by settlements, with the largest of these being Provo. A list of population within each urban settlement is found in Huntzinger (1971).

#### Drainage System

The drainage system within the area includes Salt Creek, Santaquin Creek, Payson Creek, Spanish Fork River, Hobbie Creek, Provo River, American Fork River, Dry Creek, and all tributaries between these streams as shown in Figure 2.2. Of these streams, the most important ones are the Provo River and the Spanish Fork River. The locations of important gaging stations for the streams within the area also are shown in Figure 2.2, with the name of each station listed in Table 2.2.

The Provo River, which drains an area of 680 square miles, originates at the western end of the Uinta Mountains, east of Kamas, Utah, and flows southwesterly about 60 miles past the south end of Kamas Valley, through Heber Valley, down Provo Canyon, and finally discharges into Utah Lake. The natural flow of the river averages about 260,000 acre-feet annually measured at Vivian Park below the confluence with South Fork.

The Spanish Fork River heads in the Wasatch Plateau west of Soldier Summit, flows across the southern part of Utah Valley, and also discharges into Utah Lake. The natural flow of the river averages about 150,000 acre-feet annually at Castilla, three miles downstream from Diamond Fork.

#### Reservoirs and Streamflow Regulations

Streamflow regulation has occurred along the Spanish Fork and Provo Rivers, but there is as yet little regulation on any other streams within the area. Fifteen small reservoirs have been developed at the headwaters of the Provo River, which contribute about 8,000 acre-feet of irrigation water annually. The Deer Creek Reservoir, located at the lower end of Heber Valley, releases nearly 97,000 acre-feet annually to the Provo River and provides

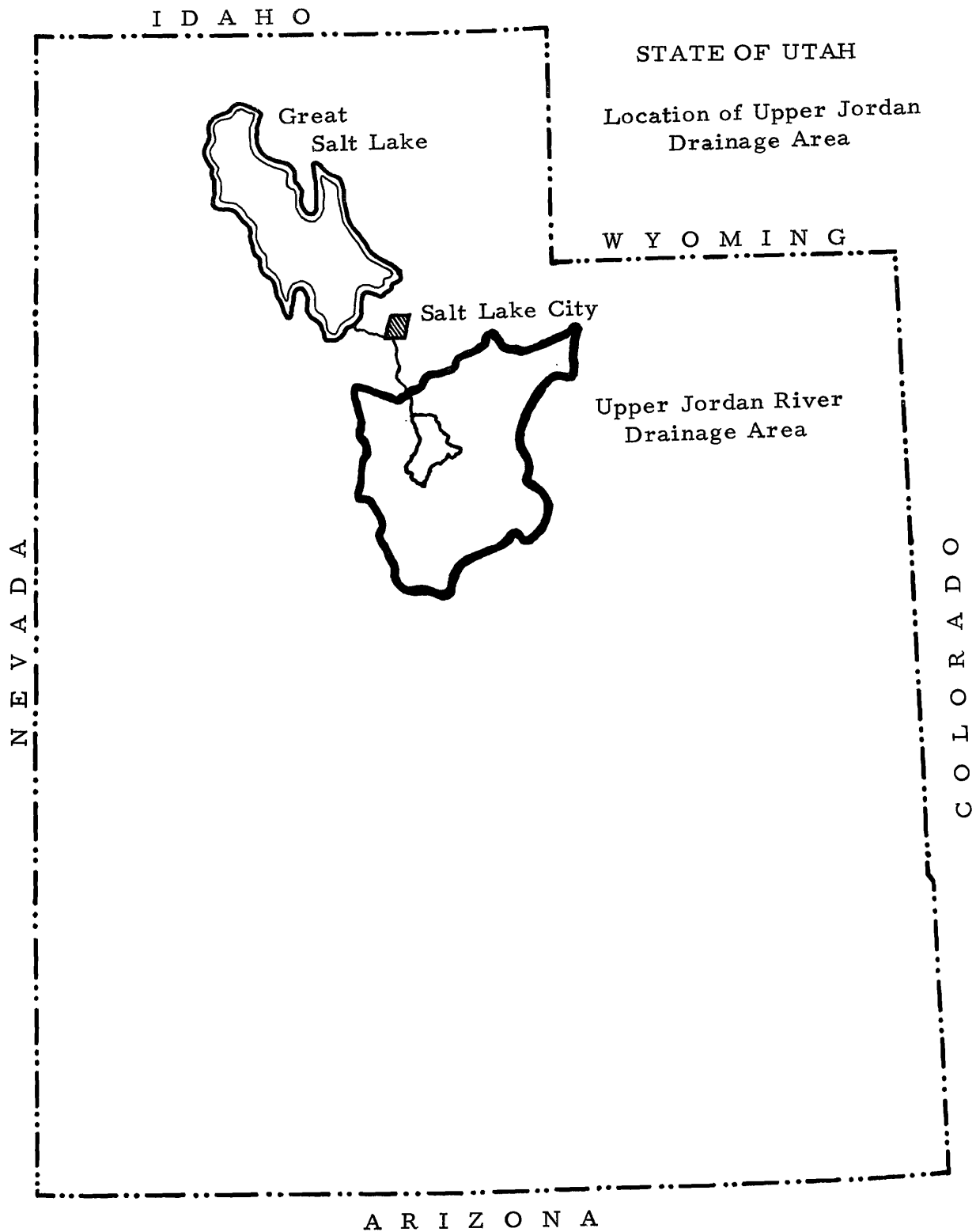


Figure 2.1. Location of the Upper Jordan Drainage area.

Table 2.1. Climatological characteristics of the Upper Jordan Drainage area (Huntzinger, 1971).

Station	Elevation ft.	Mean Annual Precip., In.	Mean Annual Temp., °F	Median frost free period <sup>a</sup>	
				Dates	Days
Utah Lake (Lehi)	4497	9.82	48.6	May 16 to Sep 24	132
Provo	4545	12.81	49.6	May 19 to Sep 22	127
Elberta	4690	10.22	50.6	May 14 to Oct 1	141
Spanish Fork PH	4711	16.79	52.0	May 1 to Oct 15	168
Lower American Fork PH	5044	16.45	52.2	Apr 30 to Oct 21	175
Heber	5593	15.05	44.5	Jun 19 to Sep 4	78
Snake Creek PH	5950	22.25	43.3	Jun 10 to Sep 4	87
Soldier Summit	7460	16.09	38.7	Jun 19 to Aug 13	56

<sup>a</sup> 50 percent probable chance that 32°F will occur after indicated dates.

Table 2.2. Hydrologic measuring stations in the Upper Jordan Drainage area.

Station No.	Station Name
STREAM GAGING STATIONS	
9-2820	Strawberry tunnel at west portal, near Thistle
10-1520	Spanish Fork near Lake Shore
10-1525	Hobble Creek near Springville
9-2725	Duchesne tunnel near Kamas
10-1535	Provo River near Kamas
10-1538	North Fork Provo River near Kamas
10-1540	Shingle Creek near Kamas
10-1545	Weber-Provo diversion canal near Woodland
10-1550	Provo River near Hailstone
10-1590	Dear Creek Reservoir near Charleston
10-1595	Provo River below Deer Creek Dam
10-1630	Provo River at Provo
10-1650	American Fork (River) near American Fork
10-1665	Utah Lake near Lehi
10-1670	Jordan River at narrows, near Lehi
WEATHER STATIONS	
2057	Dear Creek Dam
2418	Elberta
3183	Geneva Steel No. 2
3809	Heber
4467	Kamas
7068	Provo Radio KOVO
7846	Silver Lake
8973	Utah Lake (Lehi)

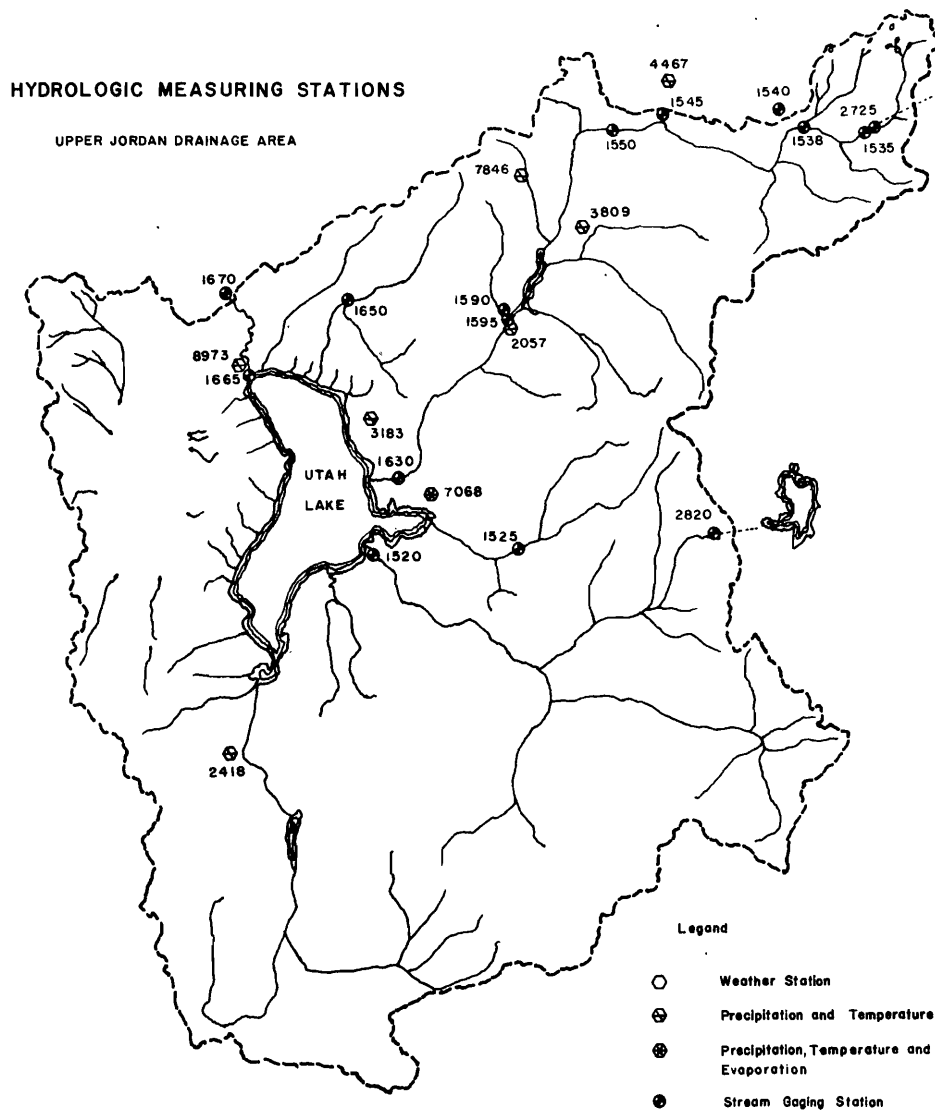
municipal and industrial water in Salt Lake County through the Salt Lake aqueduct. The Weber-Provo Diversion Canal diverts Weber River water to the Provo River basin, and excess water in the Duchesne River is diverted through Duchesne Tunnel to the Provo River. The Strawberry Reservoir, located in the Uintah Basin, also provides interbasin export through the Strawberry Tunnel into the Diamond Fork River, a tributary of the Spanish Fork River.

Mona Reservoir provides the only significant regulation of a minor stream in the drainage area. This reservoir is located on Currant Creek at the northern edge of Northern Juab Valley. It stores return flows from Northern Juab Valley and Currant Creek flows to supply the Elberta-Goshen irrigation district in the Southern Utah Valley.

### Future Outlook

Operation studies in the Upper Jordan River drainage indicate that streamflows in the area need to be augmented and regulated in order to provide sufficient water for projected future requirements (U.S. Bureau of Reclamation, 1964). These requirements include: (1) the replacement storage required for stabilization of the 15 small reservoirs located at the headwaters of the Provo River; (2) additional irrigation water for the area; (3) water to maintain certain minimum streamflows for fish life; and (4) a supply of 70,000 acre-feet for municipal and industrial purposes in northern Utah County and Salt Lake County. These additional water requirements led to





**Figure 2.2. Hydrologic measuring stations in the Upper Jordan Drainage area.**

the development of proposals which involve the Jordanelle Reservoir and the interbasin importations of water from Weber River, Duchesne River, and Strawberry Reservoir. The Bureau of Reclamation has attempted to evaluate these proposals and to select a proper plan for

development. However, the problem is so complex and the possible alternatives so numerous, that additional study still is needed to better understand the behavior of the water distribution system, and to select a suitable plan for developing and managing the available water resources.

## CHAPTER III

### MATHEMATICAL MODELS

#### General Considerations

In essence, a simulation analysis is intended to reproduce the behavior or performance of particular variables and processes within the prototype system under study. The more closely the simulation model approximates the real world, the more useful is the prediction obtained from the model.

Simulation models are classified as being either physical or mathematical in nature, depending on the simulation technique. A physical model is a physical representation of the prototype system under the appropriate time and space scaling rules of similitude. Mathematical simulation is achieved by using arithmetic relationships to represent the various processes and functions of the prototype system, and by linking these equations into a systems model. A mathematical model is easily synthesized by means of modern electronic computers. Computer simulation has the following important advantages:

1. The system can be non-destructively tested.
2. Proposed modifications of existing systems can be tested.
3. Many proposals can be studied within a short time period.
4. Hypothetical system designs may be tested for feasibility or comparison with alternate systems.
5. Insight into the system being studied is increased. In particular, the relative importance of various system processes and input functions is suggested.

#### Model Development

In the development of a hydrologic simulation model, mathematical expressions for the important processes existing in the system are derived and linked by the equations of conservation of mass and/or momentum. For this study, advantage was taken of the simulation models already developed by Riley et al. (1966 and 1967). These models were modified to include water right constraints, and to provide for increased flexibility in using the model to examine various possible water management alternatives.

#### Time and Spatial Resolutions

The choice of time and spatial increments greatly influences the complexity of model design. When large increments are used, the effects of phenomena which change over small increments of time and space are ignored. As the time and space increments decrease, improved definition of the various processes within the system is required and the model becomes more complex.

Based upon the requirements of the study and the data available, the following spatial and time increments were employed:

1. The entire drainage was divided into seven subbasins, of which six subbasins are in the Provo River Basin.
2. A time increment of one month was used for the entire study.

#### Hydrologic Balance

Interrelations of the various components of a hydrologic system are achieved by the principles of continuity of mass and momentum. Due to the relatively low velocity of flows within a hydrologic system and the large time increment adopted for the model, the effects of momentum are neglected. Thus, the system is linked only by the continuity of mass concept, which is expressed as:

$$\text{Change in storage} = \text{inflow} - \text{outflow} \quad \dots (3.1)$$

Applying this equation to a hydrologic unit yields a hydrologic balance which is represented schematically in Figure 3.1. Development of the hydrologic model consists of representing, with mathematical expressions, the physical processes which influence the terms in Equation 3.1.

#### Model Boundaries

A subbasin consists of a hydrologic unit within the main drainage system under investigation. Thus, it is possible to divide a river basin into a series of subbasins with water flows cascading from one to the other in the downstream direction. In this study the modeled area within each subbasin includes only the valley bottom (see Figure 3.2). It is this area that is most subject to the management activities of man, and exclusion of the

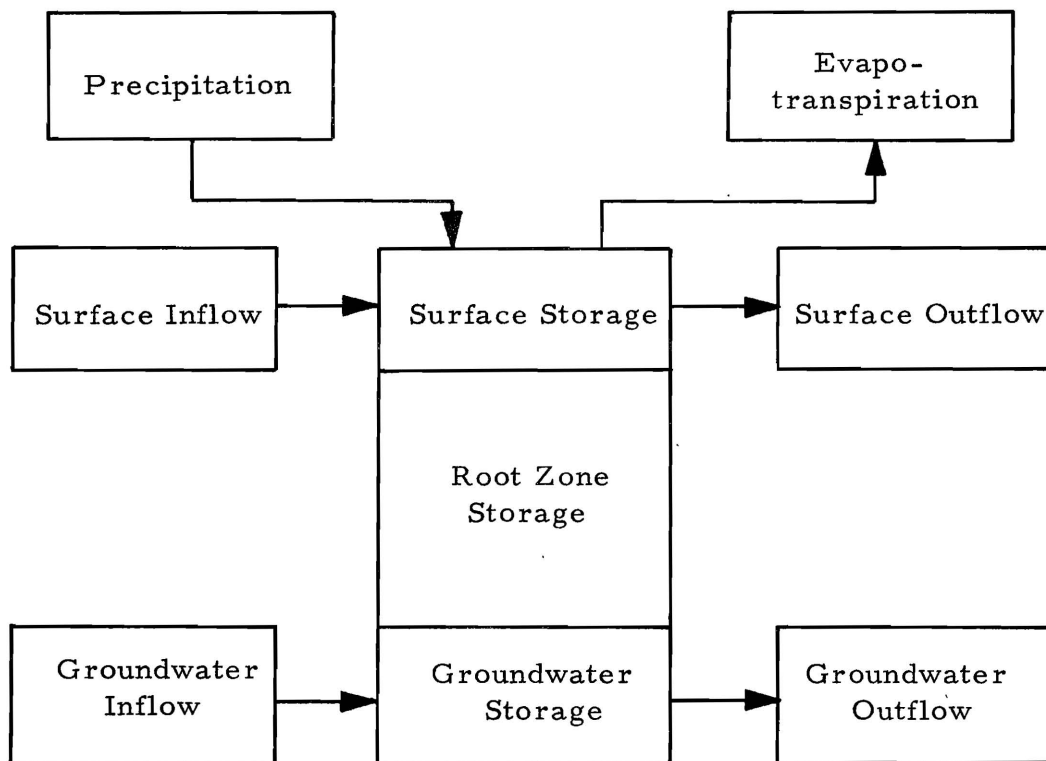


Figure 3.1. A simplified diagram of the hydrologic balance.

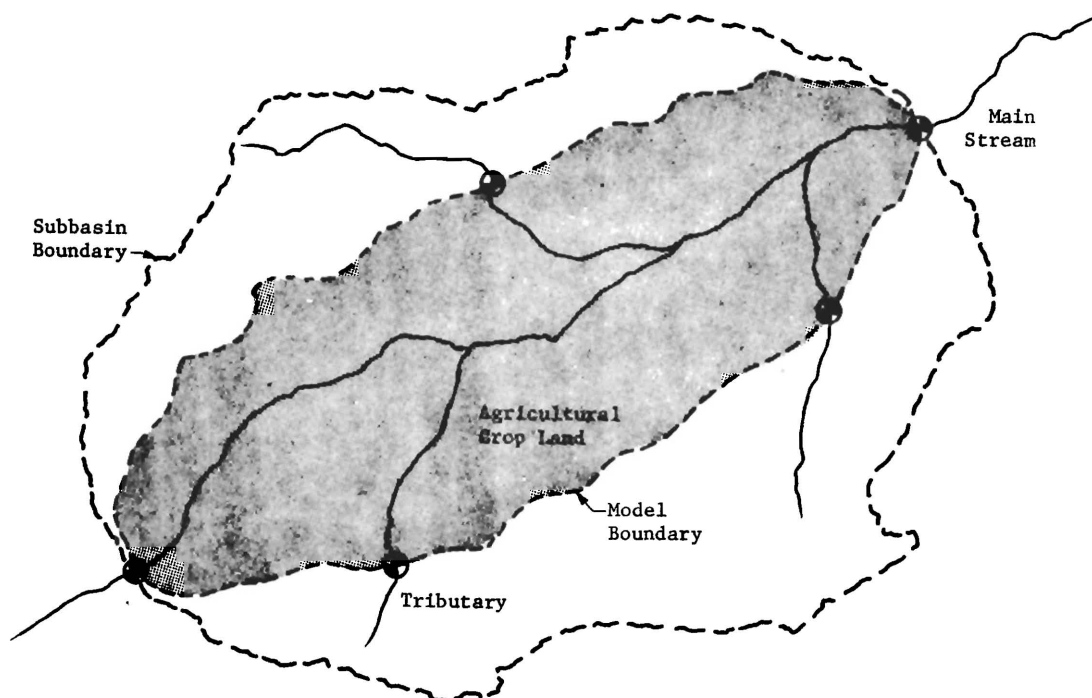


Figure 3.2. Modeled agricultural area within the subbasin.

surrounding watersheds reduces the size of the model. However, in modeling the valley bottom the surrounding watershed areas are considered from the standpoint of their surface and subsurface contributions to the valley floors.

### Model Components

A mathematical model which simulates a complex system such as the hydrologic processes of a natural watershed consists of a number of model components, each of which describes a particular phenomenon. The following is a brief description of the important components of the model which are illustrated by Figure 3.1.

#### Precipitation

Precipitation is the original source of all inputs to a hydrologic unit. Measurements of precipitation are recorded and published by the U.S. Weather Bureau. Such records represent point measurements of precipitation and the use of such data in the model requires converting the data to an average over a specified area. The conversion techniques commonly used include the Thiessen and isohyetal methods. A modified isohyetal technique using the normal isohyetal map was used to estimate average precipitation for each subbasin.

Missing precipitation data are estimated by the normal-ratio method (Paulus and Kohler, 1952) which utilizes information from nearby stations as follows:

$$P_x = \frac{1}{3} \left[ \frac{N_x}{N_a} P_a + \frac{N_x}{N_b} P_b + \frac{N_x}{N_c} P_c \right] \quad (3.2)$$

in which

- x = the station with missing data
- N = normal annual precipitation at each station indicated
- P = precipitation at each station indicated over a desired period of time. Three nearby stations are used in this example.

In the present study, precipitation was assumed to occur in the form of rain or snow, and an air temperature criterion was used to indicate the form of precipitation. This index temperature was identified for each subbasin through the model calibration procedure.

#### Snowmelt

Numerous theoretical and rational formulas have been developed to calculate snowmelt based on various factors, but all necessitate extensive data, and thus their general use is restricted. For the large time increment used

in the present model of this study, an empirical relationship presented by Riley et al. (1966) was considered appropriate.

In this relationship the rate of melt is stated as being proportional to an index of available energy and the quantity of water stored as snow. Expressed in mathematical form, the relationship is:

$$\frac{d[W_s(t)]}{dt} = -k_s (T_a - T_m) \frac{RI_s}{RI_h} W_s(t) \quad (3.3)$$

in which

- $k_s$  = constant
- $RI_s$  = radiation index on a surface possessing a known slope and aspect
- $RI_h$  = radiation index for a horizontal surface at the same latitude as the particular watershed under study
- $T_a$  = surface air temperature in degrees Fahrenheit
- $T_m$  = assumed base temperature in degrees Fahrenheit at which melt begins
- $W_s(t)$  = snow storage at time t in terms of water equivalent

The ratio of the radiation indices in Equation 3.3 remains constant for a particular area. Thus, the two constant terms can be combined to yield the snowmelt coefficient:

$$K_s = k_s \frac{RI_a}{RI_r} \quad (3.4)$$

Substituting Equation 3.4 into Equation 3.3 and solving the equation, the amount of snow storage at the end of a particular time period can be expressed as:

$$W_s(1) = W_s(0) \exp \left[ -K_s (T_a - T_m) \right] \quad (3.5)$$

in which  $W_s(0)$  and  $W_s(1)$  are the snow storage at the beginning and end of the time period, respectively.

#### Temperature

Air temperature,  $T_a$ , although not directly involved with water quantities, is an important element for hydrologic study. Air temperature is used as an indicator to determine the form of precipitation and as a basic parameter for calculating snowmelt and evapotranspiration rates.

Temperature measurements are recorded and published by the U.S. Weather Bureau. For the study area, most temperature stations are located in the valley floor.

Temperature in the higher elevations was, therefore, estimated by considering a lapse rate due to elevation difference as:

$$T'_a = T_a - L (El' - El_v) \dots \dots \dots (3.6)$$

in which

- $T'_a$  = temperature in the higher elevations
- $T_a$  = temperature in the valley floor
- $L$  = lapse rate, °F/1000 feet
- $El_v$  = elevation of the valley floor in thousands of feet
- $El'$  = elevation of the higher land in thousands of feet

### Gaged Surface Inflow

A portion of the precipitation which falls upon the land moves laterally both on the ground surface and through the soil root zone until it reaches small channels. When these channels reach a stream, they combine with other flow components to form total streamflow.

Stream outflows, both computed and gaged, from upstream subbasins, are treated as gaged inflows to adjacent downstream subbasins. Within a subbasin, the gaged streamflows that flow toward the modeled area also are treated as gaged surface inflows to the model. Many streams in the study area are gaged by the U.S. Geological Survey, and recorded data were used for direct input to the computer. The gaged surface inflow to a modeling area is designated as  $Q_{gi}$ .

### Ungaged Surface Inflow

The remaining surface inflow consists of all ungaged surface runoff toward the modeling area. This ungaged inflow is estimated by a correlation procedure involving gaged streamflow, rates of rainfall and snowmelt, and a threshold rate for surface runoff. The relationship is expressed as:

$$Q_{ug} = K_1 Q_{cor} + K_2 (P_r + SM_r) + K_3 \dots (3.7)$$

in which

- $Q_{ug}$  = estimated rate of ungaged surface inflow
- $Q_{cor}$  = measured rate of flow in a stream of similar flow pattern
- $P_r$  = gaged rainfall rate
- $SM_r$  = snowmelt rate which can be determined by taking the difference of  $W_s(1)$  and  $W_s(0)$  in Equation 3.5 for each time increment
- $K_1$  = regression coefficient relating ungaged surface inflow to gaged streamflow
- $K_2$  = regression coefficient relating ungaged surface inflow to rainfall and snowmelt rates
- $K_3$  = minimum base flow for ungaged surface runoff

$Q_{cor}$  in Equation 3.7 can be selected as the flow either in a tributary of the subbasin being studied or in a stream outside of the basin. The only criterion is that the watershed of the selected stream exhibits the same general runoff characteristics as the ungaged area being simulated. The third term,  $K_3$ , in the equation accounts for the integrated effect of rainfall interception, initial infiltration, and groundwater effluent to the ungaged streams.

The total surface inflow to the modeling area is the sum of the gaged and the ungaged components. Thus,

$$Q_{si} = Q_{gi} + Q_{ug} \dots \dots \dots (3.8)$$

in which  $Q_{si}$  is the total surface inflow and the remaining terms are as previously defined.

### Groundwater Inflow

This quantity accounts for the subsurface inflow from both the adjacent upstream subbasin and the watershed area within the subbasin being studied. The component from the watershed area within the subbasin is estimated as a residual quantity and the routing characteristics are established through the model calibration procedure. Outflows from the adjacent upstream subbasin already have been estimated. The total groundwater inflow rate is designated by  $Q_{gw}$ , which is an ungaged quantity.

### Irrigation Diversions

During irrigation seasons, a large portion of the total streamflow is diverted to irrigate crop lands. In addition, water is often pumped from groundwater sources and imported from other basins or subbasins to provide sufficient irrigation water.

In the model, imports of water to the subbasin, both from other subbasins in the drainage and from outside the drainage basin, are treated as surface inflow quantities. In cases where all or a part of the imported water is applied to the land as irrigation, the imported quantity is added to the in-subbasin stream diversions for irrigation. Thus,

$$W_{sd} = W_{cd} + W_{ii} \dots \dots \dots (3.9)$$

in which

- $W_{sd}$  = irrigation diversions from surface supplies within the subbasin for use within the area
- $W_{cd}$  = irrigation diversions from streams and reservoirs within the subbasin for use within the area
- $W_{ii}$  = irrigation water imported to the subbasin for use within the subbasin

Exports of water,  $W_x$ , from the subbasin, whether for irrigation or municipal and industrial use, are treated as separate surface outflow quantities.

The total water available for the irrigation of crop lands within the modeled area is given by the expression:

$$\begin{aligned} W_d &= W_{cd} + W_{ii} + W_{pi} \\ &= W_{sd} + W_{pi} \quad \dots \dots \dots (3.10) \end{aligned}$$

in which

$W_d$  = total diversions of irrigation water for use within the subbasin  
 $W_{pi}$  = pumped groundwater for irrigation within the subbasin, and the other terms are as previously defined

#### Municipal and Industrial Diversions

Total water used for municipal and industrial purposes in a subbasin is, like the irrigation water, the algebraic sum of diversions from streams, groundwater pumping, and water that is imported for this purpose. In mathematical form:

$$W_{mi} = W_{cmi} + W_{pmi} + W_{imi} \quad \dots \dots (3.11)$$

in which

$W_{mi}$  = total diversions of water for municipal and industrial use within the subbasin  
 $W_{cmi}$  = municipal and industrial diversions from streams and reservoirs within the subbasin for use within the area  
 $W_{pmi}$  = groundwater pumped within the subbasin for municipal and industrial use within the area  
 $W_{imi}$  = water imported to the subbasin for municipal and industrial use within the area

If the terms representing diversions from streams and reservoirs and from imports are combined into a single term which represents diversions from surface sources within the subbasin,  $W_{smi}$ , Equation 3.11 becomes:

$$W_{mi} = W_{smi} + W_{pmi} \quad \dots \dots \dots (3.12)$$

#### Surface Return Flows

Canal diversions affect the time and spatial distribution of water within an irrigated area. A portion of this diverted water is evaporated directly to the atmosphere, a second part enters the soil profile through canal seepage and infiltration on the irrigated lands, and the remainder returns to the source as overland flow. Some of the water which enters the soil profile is lost through plant consumptive use. The remainder either percolates downward to the groundwater basin or is intercepted by

drainage systems. Irrigation practices, therefore, alter the distribution characteristics of a hydrologic system. The irrigation efficiency factor used in this study includes both the conveyance and application efficiencies. Thus, multiplying total diversions by this factor provides an estimate of that quantity of water which returns directly to the stream as overland flow and/or interflow. This composite irrigation efficiency factor is given by the following expression:

$$Eff = 100 - \frac{W_i}{W_d} \quad \dots \dots \dots (3.13)$$

in which

$Eff$  = water conveyance and application efficiency in percent  
 $W_i$  = rate at which diverted water enters the soil through seepage and infiltration  
 $W_d$  = total diversion rate of irrigation water for use within the subbasin

As already indicated, a portion of the water diverted for irrigation returns to the streams as overland flow and interflow. Overland flow (often termed tailwater) is surface return flow or runoff from the end of the field resulting from the application of water to the irrigated land at rates exceeding the infiltration capacity of the soil. Interflow is defined as that part of the soil water which does not enter the groundwater basin, but rather which moves largely in a lateral direction through the upper and more porous portion of the soil profile until it enters a surface or subsurface drainage channel. Both the overland flow and the interflow return to the stream channels in short distances and time consisting of usually only a few days. The distribution of canal diversions within the hydrologic system now can be expressed as follows:

$$Q_{ri} = (1 - Eff/100) W_d + N_r \quad \dots \dots (3.14)$$

or

$$Q_{ri} = (W_d - W_i) + N_r \quad \dots \dots \dots (3.15)$$

in which

$Q_{ri}$  = surface return flow which is defined as being the total of overland flow (from irrigation applications at rates exceeding infiltration capacity rates) and interflow rates  
 $N_r$  = interflow rate  
 All other quantities have been previously defined under Equation 3.13.

In model studies involving only the relatively flat lands in the valley bottoms, and further, when a large time increment, such as one month, is employed for the model, it is unnecessary to distinguish between the two components of surface runoff and interflow. Accordingly, in this study no interflow,  $N_r$ , is assumed to occur.

It is pointed out that evapotranspiration losses do not appear as such in Equations 3.14 and 3.15. These

losses are, however, considered because they are abstracted from the infiltration quantity represented by  $W_i$ . The evapotranspiration process will be further discussed in a subsequent section.

Unlike agricultural water, much of the municipal and industrial water which is not consumed is returned to the streams by surface conveyance and does not enter the groundwater system. In equation form, municipal and industrial return flow can be expressed as:

$$Q_{rmi} = (1 - \text{Eff}_{mi}) W_{mi} \quad (3.16)$$

in which

$Q_{rmi}$  = rate of municipal and industrial return flow  
 $\text{Eff}_{mi}$  = municipal and industrial water use efficiency which also is identified through parameter optimization  
 $W_{mi}$  is as defined in Equation 3.11.

The total surface return flow,  $Q_{rt}$ , thus, can be expressed as

$$Q_{rt} = Q_{ri} + Q_{rmi} \quad (3.17)$$

#### Available Soil Moisture

The usual definition of available soil moisture capacity is the difference between the field capacity and the wilting point of the soil. Water within this range is available for plant use, and is termed available soil moisture. The field capacity is defined as the soil moisture content after gravity drainage has occurred. Most of the gravity water drains rapidly from the soil thus affording plants little opportunity for its use. The wilting point represents the soil moisture content when plants are no longer able to abstract water in sufficient quantities to meet their needs, and permanent wilting occurs. Available soil moisture can be expressed in several units but in this report it carries the unit of depth in inches.

*Sources of available water.* Basically, moisture in the soil is derived from filtration, which is the passage of water through the soil surface into the soil profile. The water available for infiltration at the soil surface is derived from three sources, namely, effective precipitation in the form of rain,  $P_r$ , snowmelt,  $SM_r$ , and irrigation water,  $W_i$ . Because of the flat topography of the lands in the valley bottoms, it is assumed that all water from rainfall and melting snows on the land surface enter the soil mantle through the infiltration process. In the case of irrigated crops, the most important source of available soil moisture is water which is diverted to the agriculture lands. The rate at which water from this source enters the soil profile through canal seepage and infiltration has been designated as  $W_i$ . Thus, the total water available for infiltration into the soil,  $W_{it}$ , can be written as:

$$W_{it} = W_i + P_r + SM_r \quad (3.18)$$

in which all quantities are as previously defined.

*Available soil moisture quantities.* The maximum quantity of water in a soil available for use by plants is a function of the moisture holding capacity of the soil and the average rooting depth or extraction pattern of the plant.

The basic forces involved in the absorption of water by plants are osmotic, imbibitional, metabolic, and transpiration pull (Thorne and Peterson, 1954). These forces basically define the soil moisture tension or "pull" that must be exerted by the plant to remove water from the soil. Of these forces the principal one is the osmotic pressure created within plant root cells. Opposing these forces are those exerted on the moisture by the soil particles. The forces exerted by the plants vary with different plants, soils, and climates, but the average maximum force which plants can exert in obtaining sufficient water for growth is approximately 15 atmospheres of pressure. At field capacity where water is readily available for plant use, the average soil moisture tension is only about 0.1 atmosphere. However, the soil moisture tension or "pull" plants exert in their quest for water is in itself no indication of the amount of available water contained by the soil. The actual amount of water held by the soil at any given tension value is a function of the soil type.

Determination of the soil depth effectively utilized by a plant is based on the average rooting depth or the average moisture extraction pattern. The soil moisture available for extraction depends on the moisture holding capacity of the soil and the extraction pattern. The typical agriculture crop extracts 70 percent of its moisture from the upper 50 percent of the soil penetrated by the plant roots. Average or typical rooting depths for various plants are reported by McCullock et al. (1967). Illustrative depths include 4 to 6 feet for alfalfa, 4 feet for grains and corn, and 2 to 3 feet for pasture. The average available soil moisture capacity of the irrigated lands was estimated for each subbasin.

Under normal circumstances, additions to available soil moisture storage occur through the infiltration process,  $W_{it}$ . Abstractions or depletions from available soil moisture storage occur through evapotranspirational losses,  $ET_r$ , and deep percolation,  $DP_r$ . The assumption is made, however, that deep percolation does not occur until the soil moisture capacity is reached. Thus, the soil moisture storage existing at any time,  $t$ , can be stated:

$$M_s(t) = (W_{it} - ET_r - DP_r) dt \quad (3.19)$$

The processes of evapotranspiration and deep percolation are discussed in the following sections.

## Evapotranspiration

Blaney and Criddle (1950) developed a simple formula for calculating evapotranspiration using temperature and daylight hours. This formula has been widely applied in the arid western states of the country. The equation is written as:

$$U = KF \quad \dots \dots \dots (3.20)$$

in which

- U = monthly potential consumptive use
- K = monthly coefficient which varies with type of crop
- F = monthly consumptive use factor and is given by the following equation:

$$F = \frac{T_a P}{100} \quad \dots \dots \dots (3.21)$$

in which

- $T_a$  = mean monthly air temperature in degrees Fahrenheit
- P = monthly percentage of daylight hours of the year

Phelan (1962) modified the Blaney-Criddle formula by dividing the monthly coefficient, K, into a crop

coefficient,  $K_c$  and a temperature coefficient,  $K_t$ . Expressed mathematically, it is:

$$K = K_c K_t \quad \dots \dots \dots (3.22)$$

The value of  $K_t$  is obtained from an empirical relationship depending on temperature and is expressed as:

$$K_t = (0.0173 T_a - 0.314) \quad \dots \dots \dots (3.23)$$

Where  $T_a$  is the mean monthly temperature in degrees Fahrenheit. The crop coefficient,  $K_c$ , is a function of crop species and stage of growth. Values of  $K_c$  are obtained from crop growth stage coefficient curves such as the one shown in Figure 3.3 for dry beans. Similar  $K_c$  curves are available for many agricultural crops (Soil Conservation Service, 1964).

The modification by Phelan (1962) of the Blaney-Criddle equation for estimating potential evaporation rate,  $ET_{pr}$ , is expressed as:

$$ET_{pr} = \left[ K_c K_t \frac{T_a P}{100} \right] \quad \dots \dots \dots (3.24)$$

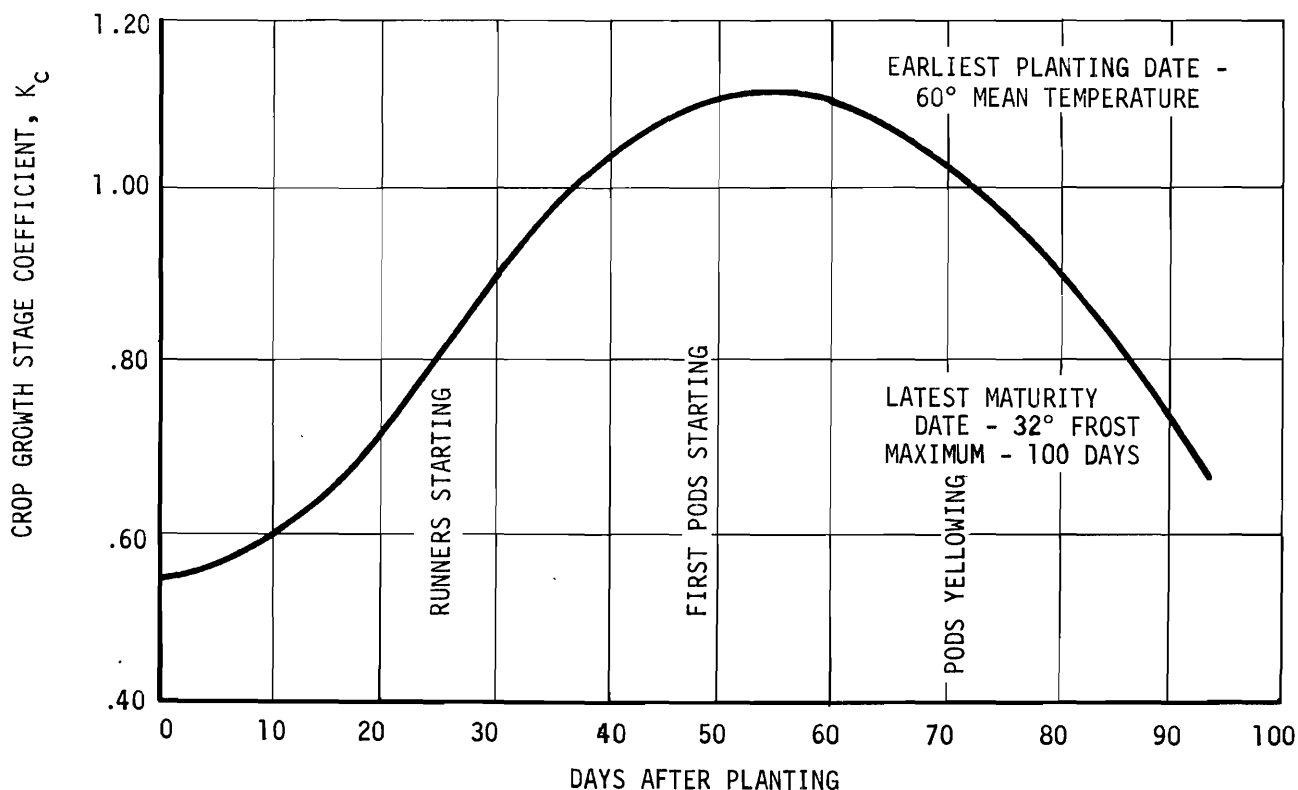


Figure 3.3. Crop growth stage coefficient curve for dry beans.



An additional coefficient,  $K_u$ , was introduced to account for the effect of elevation on evapotranspiration as suggested by Hargreaves (1973). Equation 3.24 then becomes:

$$ET_{pr} = K_u K_c K_t T_a P / 100 \dots (3.25)$$

This equation was adopted for this study and was used to estimate monthly potential evapotranspiration rates.

The actual evapotranspiration depends in part on available moisture in the soil. Research at the U.S. Salinity Laboratory in California (Gardner and Ehlig, 1963) indicates that evapotranspiration occurs at the potential rate through approximately two-thirds of the range of available moisture in the root zone. When this point in the available moisture range is reached, soil moisture becomes a limiting factor, and thereafter, the actual evapotranspiration rate lags the potential rate with a virtually linear relationship between available soil moisture content and evapotranspiration rate.

Based on this finding, Riley, Chadwick, and Bagley (1966) expressed the actual evapotranspiration rate as:

$$ET_r = ET_{pr}, \text{ when } M_s(t) \geq M_{es} \dots (3.26)$$

and

$$ET_r = ET_{pr} \frac{M_s(t)}{M_{cs}} \text{ when } 0 \leq M_s(t) \leq M_{es} \dots (3.27)$$

in which

$ET_r$  = actual evapotranspiration rate  
 $ET_{pr}$  = potential evapotranspiration rate  
 $M_{es}$  = limiting soil moisture content (measured above wilting point) below which actual evapotranspiration rate is less than the potential evapotranspiration rate  
 $M_{cs}$  = soil moisture holding capacity measured between the wilting point and the field capacity  
 $M_s(t)$  = soil moisture in the root zone at any time,  $t$ , measured above the wilting point, and is given by

$$M_s(t) = M_s(0) + (W_{it} - ET_r) \Delta t \dots (3.28)$$

in which

$M_s(0)$  = initial soil moisture measured above the wilting point and the other terms are as defined previously

For phreatophytes which grow mostly along stream courses and on wet soils, the assumption was made that the potential evapotranspiration rate always occurs. Thus, evapotranspiration by phreatophytes is designated as  $ET_{ph}$ .

### Deep Percolation

The final independent term,  $DP_r$ , of Equation 3.19 represents the rate of deep percolation. Percolation is simply the movement of water through the soil. Deep percolation is defined as water movement through the soil from the plant root zone to the underlying groundwater basin. The dominant potential forces causing water to percolate downward from the plant root zone are gravity and capillary. Water is removed quickly by gravity from a saturated soil under normal drainage conditions. Thus, the rate of deep percolation,  $DP_r$ , is most rapid immediately after irrigation when the gravity force dominates, and decreases constantly, continuing at slower rates through the unsaturated conditions. Because the capillary potential applies through all moisture regimes, deep percolation continues, though at low rates, even when the moisture content of the soil is less than field capacity (Willardson and Pope, 1963).

Because of lack of data in the study area regarding deep percolation rates in the unsaturated state, and in order to simplify the model, the assumption was made that deep percolation occurs only when the available soil moisture is at its capacity level. In most cases, this assumption causes only slight deviation from prototype conditions. Thus, for this model, the deep percolation rate is expressed as:

$$DP_r = 0, \text{ when } M_s(t) \leq M_{cs} \dots (3.29)$$

or

$$DP_r = (M_s(t) - M_{cs}) / \Delta t, \text{ when } M_s(t) > M_{cs} \dots (3.30)$$

in which  $M_s(t)$  is as previously defined and other terms are

$DP_r$  = rate of percolation  
 $M_{cs}$  = as defined in Equation 3.27  
 $\Delta t$  = time increment

### Net Groundwater Recharge

As already indicated, inflows to the groundwater storage reservoir within a subbasin occur as percolation from the agricultural lands, and as ungaged subsurface inflows from both the watershed area within the subbasin and the adjacent upstream subbasin. Thus, inflow rate to the groundwater basin,  $Q_{gw}$ , is given as follows:

$$Q_{gw} = Q_{ss} + Q_{go} \dots (3.31)$$

in which

- $Q_{ss}$  = subsurface inflow rate to the modeled area from the watersheds within the subbasin  
 $Q_{go}$  = subsurface inflow rate from the adjacent upstream subbasin

The quantity  $Q_{go}$  is further discussed in the next section under the heading "Groundwater Outflows." Subsurface inflows from the watershed areas within the subbasin,  $Q_{ss}$ , are estimated by assuming that a certain portion of the rainfall and snowmelt percolates into the ground and that this percolated water is routed through the subsurface soil according to a linear reservoir relationship before it enters the groundwater storage. In mathematical form, this recharge is expressed as:

$$Q_{ss} = I_r + (Q_{sg} - I_r) \text{EXP} (-t/K_{ss}) \quad (3.32)$$

in which

- $Q_{sg}$  = initial recharge rate to the groundwater basin from the watershed areas  
 $t$  = time  
 $K_{ss}$  = storage coefficient for subsurface routing through the soil  
 $I_r$  = rate of supply from percolation on the watershed areas

$I_r$  is computed as follows:

$$I_r = C_i(P_r + SM_r) \quad (3.33)$$

in which

- $C_i$  = a constant coefficient identified through the parameter optimization procedure and the other terms are as defined previously.

The net recharge to the groundwater storage,  $Q_{gf}$ , is thus expressed as:

$$Q_{gf} = Q_{gw} + DP_r - Q_{pi} - Q_{pmi} \quad (3.34)$$

in which all terms are as previously defined.

### Groundwater Outflows

The rate of outflow from the groundwater reservoir is calculated by routing the net groundwater recharge,  $Q_{gf}$ , in Equation 3.34 through a linear reservoir. In equation form, this quantity is expressed as:

$$Q_{ga} = Q_{gf} + (Q_{gao} - Q_{gf}) \text{EXP} (-t/K_g) \quad (3.35)$$

in which

- $Q_{ga}$  = total groundwater outflow including groundwater effluent as base flow and lateral groundwater outflow  
 $Q_{gao}$  = initial total groundwater outflow  
 $K_g$  = storage coefficient for the linear reservoir  
 $t$  = time

and  $Q_{gf}$  is as previously defined by Equation 3.34.

Assuming that a certain portion of the total groundwater outflow joins the main stream as base flow, this quantity is expressed as:

$$Q_{bf} = K_{bf} Q_{ga} \quad (3.36)$$

in which

- $Q_{bf}$  = base flow  
 $K_{bf}$  = base flow coefficient identified through the parameter optimization procedure.

The subsurface groundwater outflow component (usually to the adjacent downstream subbasin),  $Q_{go}$ , is, therefore, expressed as:

$$Q_{go} = Q_{ga} - Q_{bf} \quad (3.37)$$

### Surface Outflow

The surface outflow from a subbasin is the flow remaining in the streams at the lower end of the subbasin. This quantity is composed of surface inflow to the subbasin which is not diverted, the return flow from municipal, industrial, and agricultural uses, and the base flow from groundwater. In equation form, the surface outflow,  $Q_{so}$ , is expressed as follows:

$$Q_{so} = Q_{si} + Q_{ri} + Q_{rmi} + Q_{bf} - W_{sd} - W_{smi} + W_{ii} + W_{imi} - W_x + \Delta S \quad (3.38)$$

in which

- $Q_{so}$  = surface outflows from the subbasin  
 $Q_{si}$  = surface inflows in streams  
 $Q_{ri}$  = irrigation overland and interflow  
 $Q_{rmi}$  = municipal and industrial return flows  
 $Q_{bf}$  = base flow  
 $W_{sd}$  = surface diversions for irrigation  
 $W_{smi}$  = municipal and industrial diversions from surface supplies  
 $W_{ii}$  = imports for irrigation  
 $W_{imi}$  = municipal and industrial imports  
 $W_x$  = exports  
 $\Delta S$  = change in surface storage within the basin, with increases in surface storage here being assigned a negative value

### Total Outflow

If subbasins are selected such that there exists no flow of subsurface water past the gaged outflow point, the hydrograph of total outflow,  $Q_{to}$ , is given by Equation 3.38. This situation is assumed to exist at reservoir sites within the basin because of construction measures taken to eliminate subsurface flows under the dams which create the reservoir. For this reason, whenever possible, sub-

basins are terminated at the outfall of a reservoir. These sites thus enable a check to be made on groundwater inflow rates to the subbasin as predicted from verification studies involving models for one or more upstream subbasins.

Where possible, the termination or outlet point of subbasins is taken at a stream gaging station. However, it is possible that groundwater flow occurs in the streambed alluvium beneath the surface channel. For these basins,

the total system outflow can be written as:

$$Q_{to} = Q_{so} + Q_{go} \dots \dots \dots (3.39)$$

in which

- $Q_{so}$  = rate of surface outflow from the sub-basin (Equation 3.38)
- $Q_{go}$  = rate of subsurface or groundwater outflow from the subbasin (Equation 3.37)

## CHAPTER IV

### COMPUTER IMPLEMENTATION

Electronic computers can be classified into three main categories, analog, digital, and hybrid. The analog computer consists basically of high-gain amplifiers used in conjunction with simple resistor-capacitor circuits. In addition, special devices, such as function multipliers, function generators, diodes, and relays of various types are used as auxiliary elements for simulation of more complex systems. By connecting these devices through a program "patch panel" so that the circuit equations have the same mathematical form as the equations of the problem, the prototype is simulated. Simulation of a prototype system by using an analog computer has the advantage that the dependent variables are treated in continuous form, the computations are performed in parallel, nonlinear functions can be handled easily, and direct insight into the problem system can be gained by the engineer.

In contrast to the analog computer, the digital computer performs operations in a sequential manner, and this does not have some of the advantages of analog computer described above. However, the digital computer is capable of "memorizing" coded instructions and numerical data, and of performing logical operations and decisions.

The hybrid computer combines the memory and logic capabilities of the digital computer with the high speed and nonlinear solution capabilities of the analog computer. In addition, the high speed iterative solutions and graphical display which are characteristic of the hybrid computer provide close interaction between the hydrologist and the simulation model. These features make the hybrid computer a powerful tool in the development and verification of simulation models. In the present study, therefore, the EAI 590 hybrid computer system available at the Utah Water Research Laboratory was used to develop the initial model for the study area.

After the model had been wholly developed and verified, it was converted into digital form for operation on digital computers which are more generally available than hybrid computers. The converted model consists of three separate components, namely, a parameter optimization submodel, a river basin management model, and a component which represents the operation of Utah Lake. Each of these model components, or a combination thereof, is discussed in the following sections.

#### The Parameter Optimization Submodel

Any mathematical model that simulates the hydrology of a natural watershed contains a number of parameters which require identification through model calibration. An efficient approach to model calibration is to incorporate an appropriate optimization technique into the simulation model to determine the parameter vector that provides the best objective function. In this study, a direct search optimization method was incorporated into the model, and two objective functions were selected to provide the flexibility of calibrating the model by emphasizing either the high flows or the low flows as described in the following sections.

#### Basic Considerations

Optimization programs deal with the minimization or maximization of an objective function subject to a set of constraints. In general form, this operation is usually stated as:

$$\min. f(X_1, X_2, \dots, X_n) \quad (4.1)$$

subject to a set of constraints, such as

$$G_i(X_1, X_2, \dots, X_n) \leq b_i, \\ i = 1, 2, \dots, m$$

and

$$X_1 \geq 0, X_2 \geq 0, \dots, X_n \geq 0$$

However, the optimization procedure discussed here does not optimize the use of water, but rather it identifies those values of various model parameters which best reproduce the observed historical streamflow functions. The objective function for this optimization procedure is, therefore, to minimize the simulation error, with the constraints being the formulas used in the model for simulating the hydrology and the restrictions on the continuity of mass principles.

#### Objective Function

As mentioned previously, two objective functions were included in the computer program to provide the flexibility needed for calibrating the model by emphasizing either the high flows or the low flows. These two

objective functions are described separately as follows:

1. Emphasizing high flows:

$$\min \frac{\sum_{S=1}^n \sum_{N=1}^{12} (Q_{so} - Q_{gag})^2}{Q_{gag}} \dots (4.2)$$

in which

$Q_{so}$  = simulated monthly surface outflow  
 $Q_{gag}$  = gaged monthly surface outflow  
 $\overline{Q_{gag}}$  = mean gaged monthly surface outflow  
 $n$  = number of years of simulation  
 $N$  = number of months of simulation = 12 n

The objective function of Equation 4.2 emphasizes the high flows because the simulation error is measured by the square of deviation which, for high flows, may be small percentage-wise, but generally is large in magnitude when compared to that of the low flows.

2. Emphasizing low flows:

$$\min \frac{\sum_{S=1}^n \sum_{N=1}^{12} |(Q_{so} - Q_{gag}) / \overline{Q_{gag}}|}{N} \dots (4.3)$$

in which all terms are as previously defined.

This objective function emphasizes the low flows because a small deviation during low flow periods may constitute a large ratio for deviation versus gaged flow, while a large deviation in high flows may constitute only a small ratio.

## Implementation

The parameters to be identified by the parameter optimization model include the following:

1. Snowfall temperature
2. Snowmelt temperature
3. Soil moisture holding capacity
4. Limiting soil moisture for evapotranspiration
5. Coefficient for correlation streams in estimating ungaged inflows
6. Subsurface storage coefficient
7. Groundwater storage coefficient
8. Snowmelt coefficient
9. Evapotranspiration coefficient
10. Irrigation efficiency
11. Municipal and industrial water use efficiency
12. Coefficient for rain and snowmelt in estimating ungaged inflow
13. Threshold for ungaged inflow correlation
14. Base flow coefficient, and
15. Infiltration coefficient

The procedures which are followed during the optimization procedure are as follows:

1. Determine the range of values and the number of increments for each parameter.

2. Arbitrarily select a set of initial values for the parameters, and use these values to simulate the hydrology. Select as the objective function either Equation 4.2 or Equation 4.3, and evaluate the objective function chosen on the basis of the initial parameter values selected. Tentatively store the value of the objective function thus obtained as being the "best" value.
3. Select the first parameter for examination.
4. Vary the value of the selected parameter over the entire range while holding the remaining parameters at their initial values. For each change of the parameter value, the hydrology is simulated and the objective function calculated. This objective function is compared with the best objective function stored in the memory. The better of the two is then stored in the memory together with its corresponding parameter value.
5. Reset the parameter that has just been examined to its initial value and select the next parameter as the new parameter for examination and repeat Step 4.
6. Steps 4 and 5 are repeated until all the parameters are examined and the best value for each parameter identified.
7. Use the best value identified for each parameter and operate the model to simulate the hydrology and compute the objective function. Compare this objective function with the best objective function in the storage and save the better one together with its corresponding parameter vector. This completes one phase of the optimization.
8. Set the parameters selected in Step 7 as the new initial parameters and repeat Steps 2 through 7 for second phase of the optimization. The number of phases can be arbitrarily preassigned but generally only two to three phases are required.
9. Arbitrarily select another set of parameters and repeat Steps 1 through 8. This procedure is repeated several times to ensure that the optimal parameter vector obtained is reasonably close to the global optimal.

Table 4.1 shows an example of one phase of optimization. The last column of the table indicates the gradient of the objective function with respect to the change in parameter value. This column is useful in analyzing the sensitivity of the model in terms of the influence of change in the model parameters on the response function.

Appendix A shows a complete list of the computer program for the parameter optimization submodel together with the necessary explanation for its application.

Table 4.1. Parameter optimization sample output.

Phase I				
PAR	LVL	PAR. V.	OBJ	GRAD
1	1	30.00	.02421	
1	2	31.00	.02465	.00044243
1	3	32.00	.02469	.00004151
1	4	33.00	.02490	.00021237
1	5	34.00	.02521	.00030635
2	1	24.00	.02163	
2	2	25.00	.02283	.00122253
2	3	26.00	.02469	.00183722
2	4	27.00	.02549	.00080181
2	5	28.00	.02618	.00068536
3	1	8.00	.02528	
3	2	9.00	.02498	-.00030399
3	3	10.00	.02459	-.00028772
3	4	11.00	.02441	-.00027815
3	5	12.00	.02406	-.00035038
4	1	4.00	.02469	
4	2	5.00	.02487	.00017751
4	3	6.00	.02502	.00013689
5	1	.02	.01792	
5	2	.03	.01871	.07888676
5	3	.04	.02010	.13916715
5	4	.05	.02209	.19945058
5	5	.06	.02469	.25973135
5	6	.07	.02789	.32001215
5	7	.08	.03169	.38029408
5	8	.09	.03610	.44057673
5	9	.10	.04111	.50085937
6	1	.80	.02469	
6	2	.90	.02449	-.00201363
6	3	1.00	.02429	-.00194668
7	1	1.40	.02615	
7	2	1.60	.02469	-.00731933
7	3	1.80	.02345	-.00620297
7	4	2.00	.02240	-.00524893
8	1	.15	.02507	
8	2	.16	.02493	-.01356936
8	3	.17	.02481	-.01257136
8	4	.18	.02469	-.01164264
8	5	.19	.02456	-.01078173
8	6	.20	.02448	-.00998899

## Calibration of the Model

The parameter optimization program is applied to a specific river basin by dividing it into subbasins, usually based on the locations of stream gaging stations. Figure 4.1 shows the Upper Jordan River drainage and the subdivision into which it was divided for this study. The relatively high resolution adopted for the Provo River basin was used because of the emphasis of this study on that basin. After calibration of the model, some of the subbasins in the Provo River basin were again divided into smaller units to correspond to selected points of interest along the river channel, as shown in Figure 4.2. The parameter values for each of these smaller units were assumed to be the same as those of the subbasin containing the unit. Table 4.2 shows the results of parameter optimization for each subbasin. The period of record used for the optimization procedure was 1964 through 1967.

In applying the parameter optimization program for model calibration, change in reservoir storage was treated as equivalent gaged streamflows. An increase in storage was treated as a negative inflow and a decrease as a positive inflow to the subbasin containing the reservoir. Precipitation and evaporation were treated as a positive and negative inflow, respectively, to the subbasin.

## Testing of Calibration Results

After the model parameters were identified for each subbasin, the model was tested for the 20 year period 1950 to 1969. Land use conditions for 1965 were assumed to apply throughout the entire test period (Hyatt et al., 1968). Figures 4.3 through 4.5 represent some of the results of this test and show comparisons between simulated and observed hydrographs for the Provo River at different locations for the period 1950 to 1953. As indicated by these figures, generally good agreement was

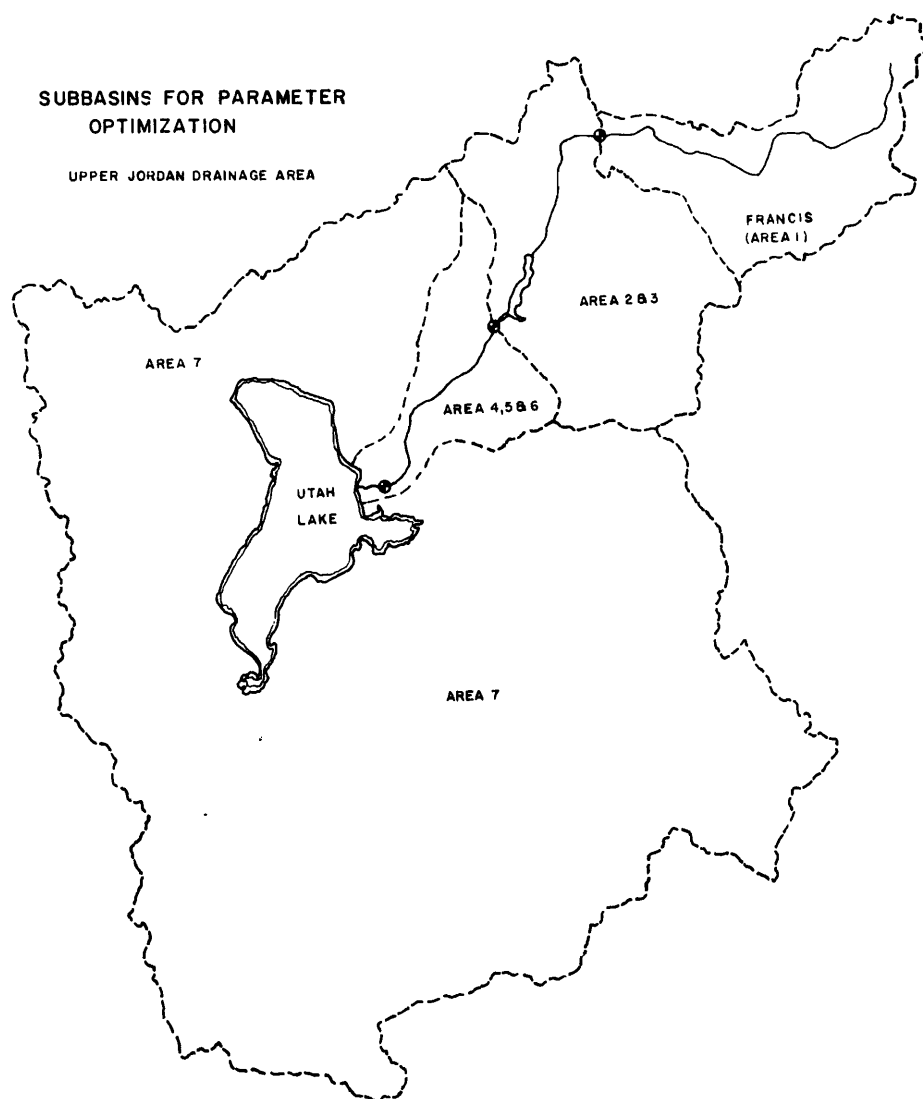


Figure 4.1. Division of the Upper Jordan River basin for parameter optimization.

achieved between observed and simulated flows. However, as shown by Figures 4.3 and 4.4, the model was not able to duplicate the exceptionally high recorded outflows at these stations for May 1952. These high runoff rates were generated by a short period of high temperatures accompanied by rain on a snowpack. The relatively short period of high temperature conditions was not reflected in the average monthly temperature used as input information to the model. For this reason, the response of the model was somewhat different from that of the real-world system. In this case, improved agreement between observed and simulated output functions at this particular point in time could be achieved by incorporating increased temporal resolution into the model.

### The River Basin Management Submodel

The river basin management model, using the optimized parameters, simulates the hydrologic responses

of the system being modeled to various water management alternatives. The model simulates, or generates, streamflow rates at different locations along the stream of interest. System processes incorporated into the model include evapotranspiration and return flow from agricultural land, soil moisture variations, reservoir storages, groundwater effluents, and other important phenomena in the hydrologic system. The model also is capable of sizing reservoirs on the basis of different water management patterns, subject to various water right constraints.

Basically, the model consists of the mathematical equations developed in Chapter III linked by the equation of continuity. In addition, necessary logic routines are included in the model to provide the flexibility of studying the effects of different water management alternatives subject to various constraints. Some important management principles included in the model are described in the following sections and a complete list of

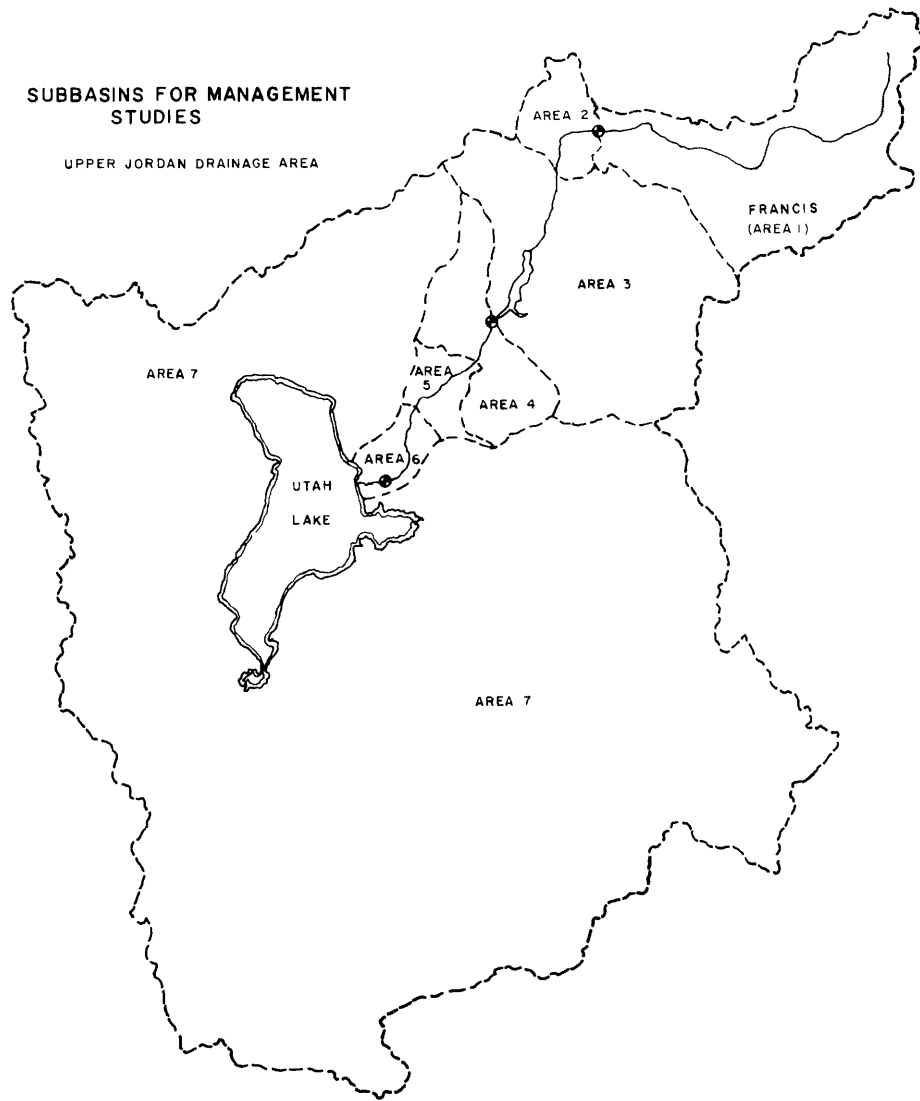


Figure 4.2. Division of the Upper Jordan River basin for management.



Table 4.2. Results of parameter optimization.

PARAMETER	Francis	Areas 2 & 3	Areas 4,5 & 6	Area 7
Snowfall Temperature	40.00	32.00	35.00	37.00
Snowmelt Temperature	30.00	26.00	25.00	33.00
Soil Moisture Holding Capacity	6.00	10.00	5.00	8.00
Critical Soil Moisture	4.00	4.00	3.00	6.00
Ungaged Stream Corre- lation Coefficient	.28	.06	.01	.84
Soil Storage Coefficient	.20	.80	1.00	1.00
Groundwater Storage Coefficient	.40	1.60	3.50	1.00
Snowmelt Coefficient	.12	.18	.18	.10
Consumptive Use Coefficient	1.00	1.10	1.24	1.20
Irrigation Efficiency	.30	.50	.60	.50
M & I Efficiency	.80	.80	.90	.80
Coefficient of Rain Plus Snowmelt for Ungaged Flow	.04	.02	.01	.01
Threshold for Ungaged Flow Correlation	.12	.20	.03	.02
Base Flow Coefficient	.40	.40	.32	.20
Infiltration Coefficient	.02	.05	.01	.01
Initial Soil Moisture	4.00	4.00	2.00	4.00
Initial Base and Ground- water Outflow	4.00	2.00	2.00	2.00
Initial Watershed Recharge	3.00	2.00	2.00	2.00

the computer program for the model is given in Appendices B and C, together with the necessary explanations for its application.

### Important Management Principles

1. *Irrigation Diversions.* Better management of water within a river basin often can be accomplished through improved management techniques. The computer

program provides two alternative ways of determining irrigation diversions for the modeled area.

The first alternative is to calculate irrigation diversions on the basis of available soil moisture and crop consumption in such a way that the soil moisture is maintained within the range between the critical soil moisture level,  $M_{es}$ , and the soil moisture holding capacity,  $M_{cs}$ . In equation form, this diversion is expressed as follows:

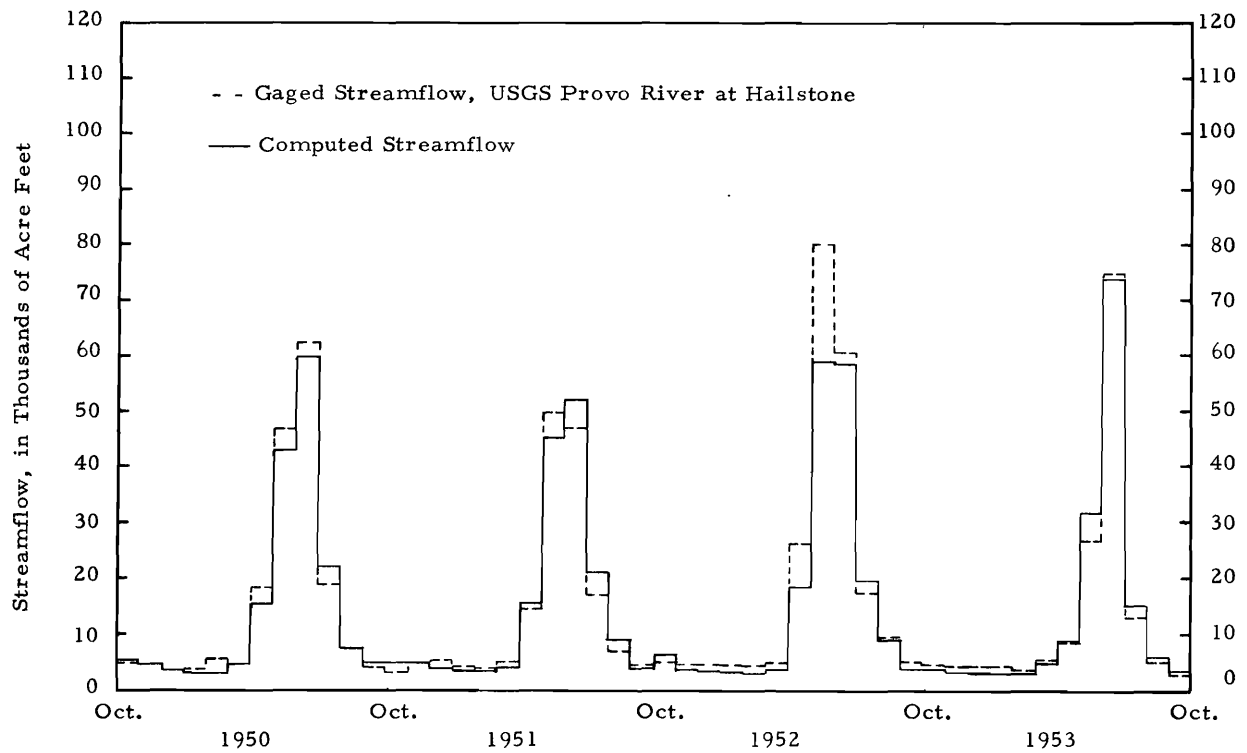


Figure 4.3. Computed and observed monthly streamflow from Francis Subbasin, 1950 - 1953.

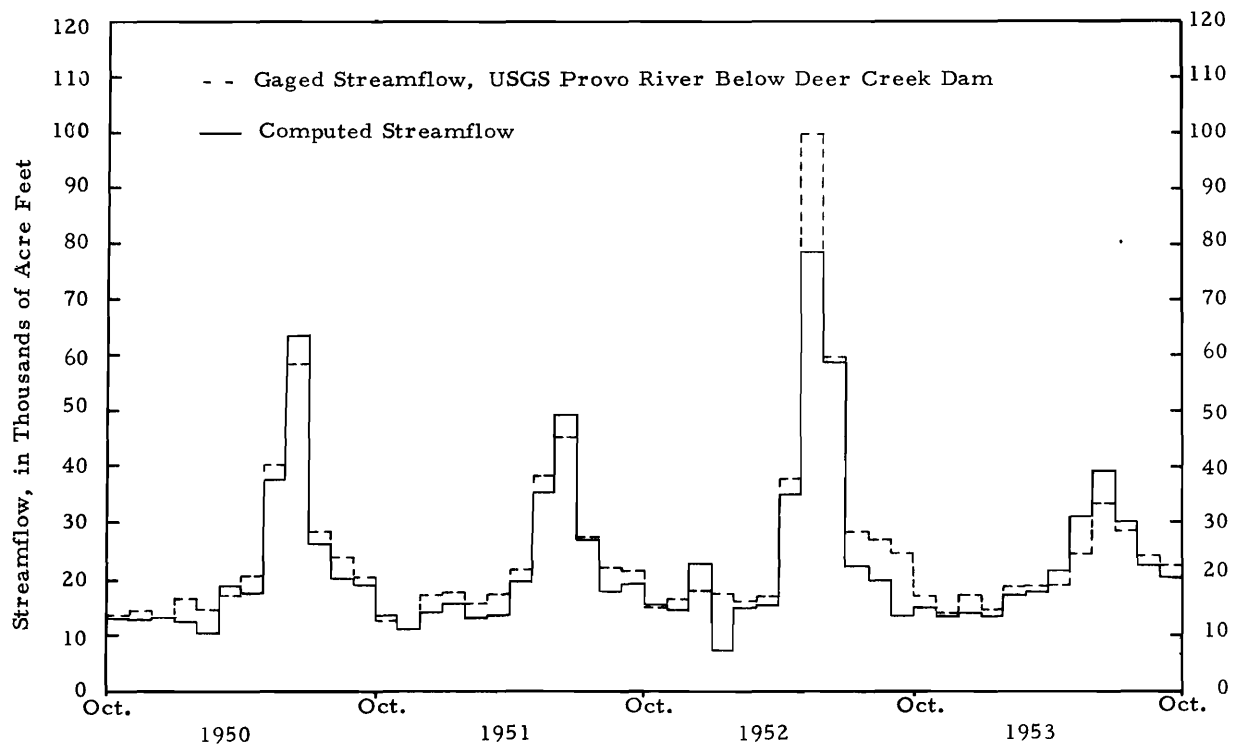


Figure 4.4. Computed and observed monthly streamflow from Area 2-3 Subbasin, 1950 - 1953.

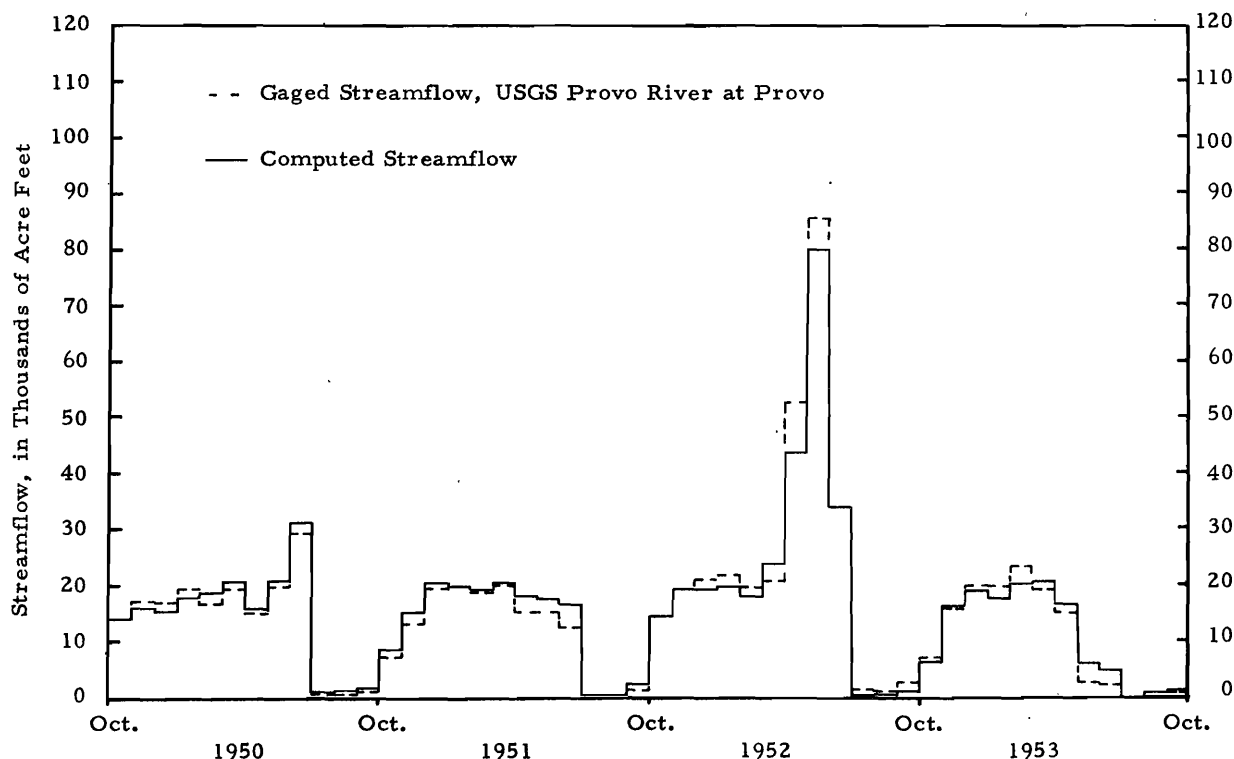


Figure 4.5. Computed and observed monthly streamflow from Area 4, 5, 6 Subbasin, 1950 - 1953.

$$ET_{pr} = P_r + SM_r + (W_d) \text{ Eff}$$

or

$$W_d = \frac{ET_{pr}}{E_{ff}} - (P_r + SM_r) \dots \dots \dots (4.4)$$

in which

- $W_d$  = total irrigation water for the subbasin
- $ET_{pr}$  = crop potential evapotranspiration
- $E_{ff}$  = irrigation efficiency
- $P_r$  = rainfall
- $SM_r$  = snowmelt

If Equation 3.10 is introduced into Equation 4.4, the expression becomes:

$$W_{cd} = \frac{ET_{pr}}{E_{ff}} - (P_r + SM_r + W_{pi} + W_{ii}) \dots \dots \dots (4.5)$$

in which the additional terms are

- $W_{cd}$  = irrigation diversions from surface supplies within the subbasin
- $W_{ii}$  = irrigation imports

All of the above terms are previously defined in Chapter III. If export waters for irrigation use are diverted from surface supplies within the subbasin, this quantity,  $W_{xi}$ , must be added to  $W_{cd}$  to obtain the total irrigation diversions from surface supplies within the subbasin under consideration.

The second alternative is to calculate the irrigation diversion separately on the basis of irrigation requirement and water right constraints and input the resulting quantities to the model.

2. *Municipal and Industrial Diversions.* If municipal and industrial diversions and the corresponding efficiency of use factor are obtained, these values need to be input to the computer program. In simulating the responses associated with future water management priorities, the anticipated municipal and industrial diversions need to be estimated separately and input to the model.

3. *Reservoir Management.* Reservoirs are constructed for various purposes which include flood control, recreation, supplying water to new users, storing high flows for low-flow augmentation, and saving water which otherwise would be lost from the system during periods of high flow and low usage. The reservoir management routine incorporated into this program allows simulation of existing or proposed reservoir operations, including

releases for downstream water rights and storage of exchange waters imported from outside basins.

Inflows to a reservoir consist of the outflow from the subbasin immediately upstream from the reservoir and the precipitation which falls directly on the reservoir. Outflows from a reservoir consist of releases and spills to the downstream channel, diversions from the reservoir above the dam, and evaporation from the reservoir surface. In the reservoir operating routine of the model, the minimum reservoir release is specified for each month on the basis of downstream water rights. This amount is released from the reservoir and an examination is made to determine whether this release is sufficient to meet all downstream requirements. If a water deficiency is found, the release is adjusted upward to meet the requirement, providing sufficient water is available in the reservoir. In high flow seasons, inflows to the reservoir may be so large as to cause the reservoir storage to exceed the maximum capacity. In this case, additional water is released from the reservoir in order to bring the reservoir storage down to its specified maximum capacity.

Under conditions when the reservoir storage approaches the minimum level, it is possible that stored water quantities are not sufficient to meet both the downstream requirements and the allowable diversions above the dam. Under this situation, it is assumed that the available storage is used to meet prior rights to the extent possible.

**4. Multiple Reservoir System.** When there are two or more reservoirs on a system, the management alternatives increase. In the program developed under this study, the operation of a sequence of reservoirs can be simulated over a wide range of management alternatives. As in the case of single reservoir, desirable flows at points below the reservoirs can be assigned and the reservoir releases adjusted to meet the requirement. In addition, a desirable storage for each reservoir can be specified for each month of the year, and the reservoir system operated in such a way that, within limits imposed by available water supplies, values in each reservoir are maintained at or above the desirable level. Maintaining a reservoir at or above a desirable storage enhances recreation opportunities and water quality.

Figure 4.6 illustrates the manner in which the desired storage and desired streamflow criteria are implemented for a two reservoir system. The system described is the Provo River basin with the proposed Jordanelle Reservoir in operation.

Under conditions when storage levels in downstream reservoirs are equal to or above minimum desired values, the system model holds excess water in the most upstream reservoir. When the storage in any reservoir drops below its desired level, water is released from the closest

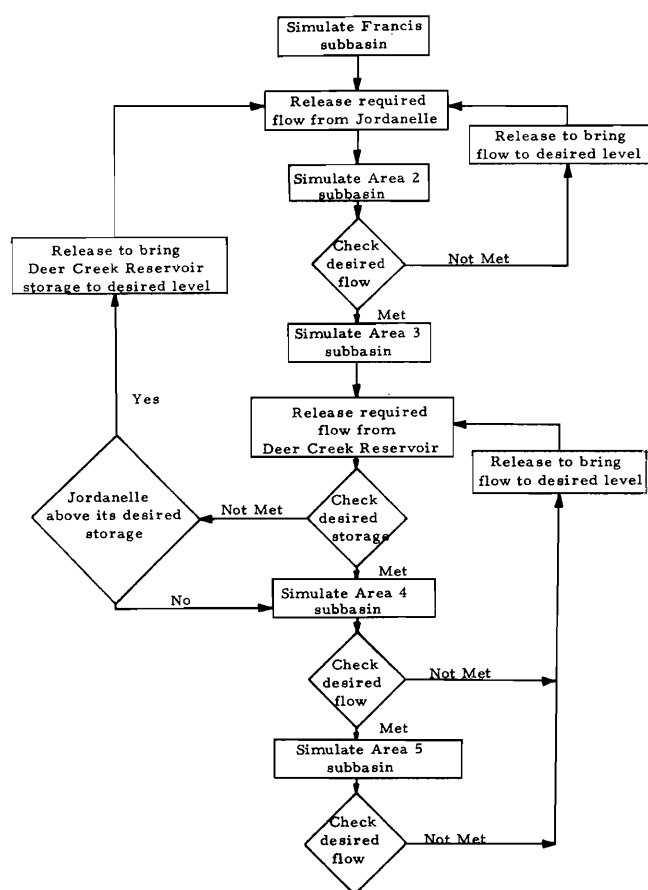


Figure 4.6. Illustration of a two reservoir system.

upstream reservoir to raise the storage to the desired level. If necessary, this process is continued in a sequential procedure through other reservoirs in the upstream direction. When all reservoirs drop below desired storage levels, available active storage is held at the highest reservoir possible on the stream system.

**5. Desired Streamflow.** Maintaining a minimum streamflow requires at least one reservoir on the system. The specified desired streamflow is designed to maintain streamflows below a reservoir above a specified level so that minimum fisheries, recreation, and other water requirements are satisfied.

In the model operation, the simulated outflow from a subbasin is compared with the specified desirable flow. When the simulated outflow is less than the desirable flow, additional necessary releases are made from one or more of the upstream reservoirs.

## Application

The river basin management model is a powerful tool for studying both existing and proposed water development systems within a river basin. In the case of this study, the usefulness of the model was demonstrated by assuming various development alternatives for the Provo River basin, as shown in Table 4.3. Run 1 of this table was designed to provide information on the degree to which the present system of storages and diversions on the river meet the water demands under the conditions of full development of the Provo River Project. The results of this run provide an indication of the water shortages that might be experienced under these conditions, and the expected demands on the Central Utah Project are thus identified.

Runs 2 through 8 were designed to investigate the effect of the Central Utah Project on the Provo River system under different management alternatives. Among the important elements studied in these runs are the following:

1. The proper size of the proposed Jordanelle Reservoir as affected by various water management alternatives as indicated by Column 2.
2. The impacts of various project demands on the system, especially on the size of the Jordanelle Reservoir, as indicated by Columns 3, 4, and 6.
3. The influence of water right constraints as indicated by Column 7.
4. The feasibility of supplying a minimum flow for fishery and recreation as indicated by Column 8.
5. The effect of the proposed water right transfer from the Olmstead Power Plant to the Central Utah Project.

The input data used in these management runs consisted basically of historical temperature, precipitation, canal diversions, and gaged streamflows for the period from 1929 to 1969. Other inputs to the model included imported water quantities from the Weber and

the Duchesne River basins, and the demands of various projects both within and outside of the Provo River basin. These data were obtained from a separate study made by the Bureau of Reclamation.

As was mentioned at the beginning of this report, the main objective of this study was to construct a generally applicable simulation model which is capable of predicting the responses of water resources development systems under a wide range of management alternatives, rather than to conduct an in-depth management study for a particular area. Available data, such as future project demands, used in the management runs discussed previously, are tentative and subject to changes. Therefore, the results of the computer runs set out by Table 4.3 are not included in this report. It is emphasized, however, that the simulation model applied well for each of these runs, and it is expected that the model will apply equally as well for a wide range of management studies in other river basins.

## The Combined Utah Lake Operation Model

There are certain specific problems associated with the operation of Utah Lake in the system under investigation. These specific problems include:

1. The effects of the diking of the Provo and Goshen Bays on the operation of Utah Lake, including:
  - a. Storage quantities in the proposed Jordanelle Reservoir. For example, diking will reduce the surface area of Utah Lake and thus presumably reduce evaporation losses from the lake. These evaporation savings might be exchanged for Provo River water which would be stored in the proposed Jordanelle Reservoir.
  - b. The water quality of Utah Lake.
2. The constraints imposed on the system by the Utah Lake compromise level.

To provide a simulation model with sufficient flexibility to answer these kinds of questions, the river basin management model was combined with the Utah Lake operation model developed by the Central Utah

Table 4.3. Development alternatives for the Provo River Basin.

RUN	JORDANELLE RESERVOIR				DEER CREEK RESERVOIR			OTHER CONSTRAINTS	
	Storage (thousand acre-feet)	Utah County M&I	Salt Lake County M&I	Head of Provo River storage stabilized?	Storage (thousand acre-feet)	Salt Lake City M&I	Bypass Flow	Fishery	Olmstead Diversion
1	Initial: 0 Desirable: 0 Maximum: 0 Minimum: 0	0	0	no	Initial: 150.0 Desirable: 150.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet	Natural Flow Plus 38,300 acre-feet	none	up to 429 cfs
2	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	Central Utah Project requirement	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet	Irrigation Season Natural Flow Plus 38,300 acre-feet  ----- Non- Irrigation Season Fishery Only	50 cfs Jordanelle Reservoir to Deer Creek Reservoir	none
3	Initial: 350.0 Desirable: 170.0 Maximum: 1,000.0 Minimum: 3.0	Central Utah Project requirement	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 120.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet			none
4	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	10,000 af/yr	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet			none
5	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	Central Utah Project requirement	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet		60 cfs Deer Creek Reservoir to Murdock Canal	none
6	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	Central Utah Project requirement	Central Utah Project requirement	no	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet			none
7	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	Winter Demand	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet			none
8	Initial: 350.0 Desirable: 170.0 Maximum: 350.0 Minimum: 3.0	20,000 af/yr	Central Utah Project requirement	yes	Initial: 150.0 Desirable: 70.0 Maximum: 150.0 Minimum: 2.8	61,700 acre-feet		Above Plus 25 cfs Murdock to Utah Lake	none

Project Office of the Bureau of Reclamation to form the combined Utah Lake operation model.

In applying this combined model, the hydrology of the drainage just upstream from Utah Lake is simulated by the river basin management model, which is now a submodel of the combined model. The simulated results are carried over to the Utah Lake operation model, which is also a subroutine of the combined model, to simulate the operation of the lake. The river basin management model has been described previously in this report. The Utah Lake operation model was developed in a separate study by the Bureau's Central Utah Project Office and the documentation is available from that office. The detailed description of this model, therefore, will not be repeated here. However, a complete list of the computer program for the combined model is given in Appendix D, together with the necessary explanations for its application. In addition, some elements which are unique to the combined model are discussed in the following paragraphs.

#### Lake Evaporation

In the river basin management model, the modified Blaney-Criddle equation (Phelan, 1962) was used to estimate evaporation from reservoir surfaces. The adoption of this equation was considered appropriate on the basis of available data and the relative importance in the

water budget of evaporation from upstream reservoirs, such as Deer Creek and Jordanelle Reservoirs. In the case of Utah Lake, however, the situation is different. The lake has an area of 96,000 acres with an average depth of only 9 feet at the compromise level. The inflow to the lake from all sources is rather moderate and is estimated at 600,000 acre-feet annually (USBR, 1964). Because of the moderate water yield of the basin and the large area of the lake, a small error in estimating the depth of evaporation will cause a large departure of the simulated hydrology from its actual magnitude. A more sophisticated and accurate method for estimating evaporation from the lake was, therefore, considered necessary and an effort was made to derive an evaporation equation based on the theories of mass transfer and energy budget as described in Appendix E. The resulting equation was applied to estimate the lake evaporation for the period of 1962 through 1969 in which the necessary data were available. A water budget analysis of the lake during that period indicated that the computed evaporation approximated well the actual evaporation. To extend the method to the period for which sufficient data, particularly solar radiation, are not available, the computed lake evaporation was correlated to the pan evaporation data available at the Lehi station near the lake. Figure 4.7 shows the resulting relationship and this relationship then was used to estimate lake evaporation in the simulation model.

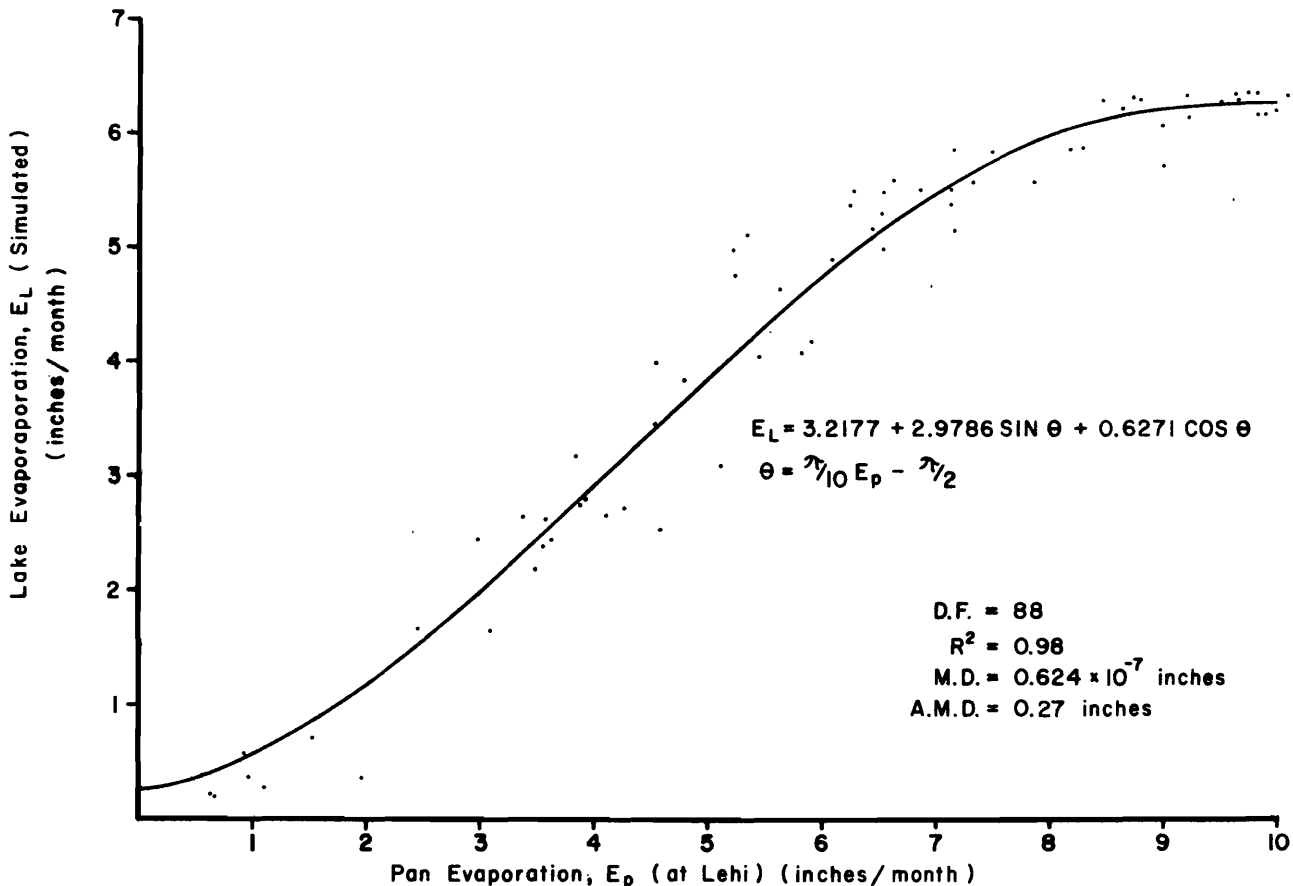


Figure 4.7. Lake and pan evaporation relationship, Utah Lake.

## Water Quality

In studying the variation of water quality in Utah Lake, it was considered most important, at the present stage of study, to analyze the budget of total dissolved solids for the lake. To estimate the flow of dissolved solids to the lake, an attempt was made to correlate the total dissolved solids (t.d.s.) content to water flow rates on an individual stream basis. Unfortunately, the attempt was not successful because of the limited salinity data available. The number of data points were so limited and the

plotting position of these points was so dispersed that no conclusive relationships could be established between the dissolved solids concentration and the flow rate. Therefore, in the management studies conducted to this point, the assumption was made that the total dissolved solids concentration in the streams does not change appreciably from year to year and for each stream an average concentration was calculated for each month of the year based on the available data. Table 4.4 shows the resulting values. These values were used in the preliminary management studies conducted under this project.

**Table 4.4. Total dissolved solids content, in ppm, of the various inflows to Utah Lake.**

Source	Month											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Provo River Inflow	288.0			281.0		361.9		210.1	247.5	284.3	295.2	293.3
Other Surface Inflow				795.3						593.2		
Groundwater Inflow						851.0						





## CHAPTER V

### SUMMARY AND CONCLUSIONS

In this report, a generally applicable computer simulation model is proposed which simulates the hydrologic responses of a water resource system to various management alternatives. Under the study reported here the model was applied to the Upper Jordan River drainage. In total the model consists of three separate components, each of which is capable of functioning as a separate entity, or model, but which comprise submodels of the overall model proposed. These three components are: (1) the parameter optimization model; (2) the river basin management model; and (3) the Utah Lake operation model. The first two submodels are general in nature and can be applied directly to any river basin. The third submodel, the Utah Lake operation model, was developed specifically to simulate the operation of Utah Lake, but with minor modifications still can be applied to other locations.

In applying the model to the study area, the area was divided into several subbasins on the basis of available data and desired degree of spatial resolution. For each subbasin the model parameters were identified by applying the parameter optimization submodel. The identified parameter values were tested by simulating subbasin outflows for a 20 year period. As indicated by Figures 4.3 to 4.5, good agreement was achieved between observed and simulated outflows for the entire test period. The river basin management model was used to simulate the hydrology of the river basin for various water management alternatives. The major processes simulated by this model include streamflows at different locations along the stream of interest, evapotranspiration and return flows from agricultural land, soil moisture variations, reservoir storages and releases, and groundwater effluents. To simulate the operation of Utah Lake, the hydrology for the area above the lake was simulated by means of the river basin management model and the results were carried over to the Utah Lake operation model developed by the Bureau's Central Utah Project Office. The resulting so-called combined Utah Lake operation model thus has the river basin management model and the Bureau's Utah Lake operation model as its two component submodels. The combined model also is capable of simulating the

variation of total dissolved solids in Utah Lake as affected by selected water resources management alternatives.

In general, the model developed under this project applied to the study area and produced meaningful predictions for the management alternatives used to test the model. It is expected that the model will function equally well over a wide range of management alternatives in any river basin to which it is applied. However, it is important to realize that any hydrologic simulation model, while providing much insight and understanding for the system under investigation, is also subject to certain limitations. For the particular model under discussion, the major limitations are:

1. A large time increment of one month was used for this model. This time increment generally is adequate for water supply studies, but is not suitable for analyses of phenomenon, such as flood flows, for which daily or even hourly variations are needed.
2. The model is deterministic in nature and the management studies made have been based on the historical records. The development of such a model was desirable because it is relatively easy to manipulate and it is capable of providing average information regarding the system. This kind of information is useful in investigating plans for the proper management for the system. However, it is necessary to realize that all hydrologic processes contain a strong stochastic element, and a historical record is no more than a particular realization of these processes over a limited time period.
3. The only water quality aspect considered in this model was the total dissolved solids content in the Utah Lake and its tributary inflows. Rather crude approximations of monthly salinity levels were developed for surface and groundwater flows. In order to improve and expand this aspect of the model, additional salinity data are needed so that predictive functions might be established for various water quality parameters.

## REFERENCES CITED

- Blaney, Harry F., and Wayne D. Criddle. 1950. Determining water requirements in irrigated areas from climatological and irrigation data. Technical Paper 96, Soil Conservation Service. U.S. Department of Agriculture. February. 48 p.
- Dalton, J. 1802. Experimental essays on the constitution of mixed gases; on the force of steam or vapor from water and other liquids in different temperature, both in a Torricellian vacuum and air; on evaporation; and on the expansion of gases by heat. Manchester Lit. 1. Soc. Mem. Proc., 5:536-602.
- Gardner, W. R., and C. F. Ehlig. 1963. The influence of soil water on transpiration by plants. *Journal of Geophysical Research* 68(20):5719-5724.
- Harbeck, G. E., Jr., and others. 1954. Water-loss investigations, Vol. 1 Lake Hefner Studies. Technical Report, USGS Paper 269.
- Harbeck, G. E., Jr., M. A. Kohler, G. E. Koberg, and others. 1958. Water-loss investigations, Lake Mead Studies. USGS Profess. Paper 298.
- Harbeck, G. E., Jr. 1962. A practical field technique for measuring reservoir evaporation utilizing mass-transfer theory, studies of evaporation. USGS Profess. Paper 272-E.
- Hargreaves, George H. 1973. The estimation of potential and crop evapotranspiration. Utah State University, Logan, Utah. 11 p.
- Huntzinger, Thomas L. 1971. Future water use model of Utah Valley. Colorado State University, Fort Collins, Colorado. 119 p.
- Hyatt, M. L., G. V. Skogerboe, and F. W. Haws. 1968. Water related land use in the Utah Lake drainage area. Report WG40-1. Utah Water Research Laboratory, Utah State University, Logan, Utah. February.
- Hyatt, M. L., G. V. Skogerboe, F. W. Haws and L. H. Austin. 1969. Hydrologic inventory of the Utah Lake drainage area. Report WG40-3. Utah Water Research Laboratory, Utah State University, Logan, Utah. November.
- Jensen, M. E., and H. R. Haise. 1963. Estimating evaporation from solar radiation. Paper 3737, Proc. ASCE, J. Irrig. and Drain. Div., 89(IR4):15-41.
- Linsley, Ray K., Jr., Max A. Kohler, and Joseph L. H. Paulhus. 1958. *Hydrology for engineers*. McGraw-Hill Book Company, Inc., New York. 340 p.
- List, R. J. 1968. *Smithsonian meteorological tables*. Smithsonian Institution Press, City of Washington.
- McCulloch, Allan W., Jack Keller, Roger M. Sherman, and Robert C. Mueller. 1967. *Ames irrigation handbook*. W. R. Ames Company, Milipitas, California.
- Meyer, A. F. 1915. Computing run-off from rainfall and other physical data. *Trans. ASCE*, 79:1056-1155.
- Paulhus, Joseph L. H., and Max A. Kohler. 1952. Interpolation of missing precipitation records. *Monthly Weather Rev.*, 80:129-133.
- Penman, H. L. 1948. Natural evaporation from open water, bare soil and grass. *Proc. Roy. Soc. London, Ser. A*. 193:120-145.
- Phelan, John T. 1962. Estimating monthly "k" values for the Blaney-Criddle formula. Presented at the Agriculture Research Service-Soil Conservation Service Workshop on Consumptive Use, Phoenix, Arizona. March 6-8. 11 p.
- Raphael, J. M. 1962. Prediction of temperature in rivers and reservoirs. *Proc. ASCE, J. Power Div.*, 88:(PO2):157-181.
- Riley, J. Paul, D. G. Chadwick, and J. M. Bagley. 1966. Application of electronic analog computer to solution of hydrologic and river-basin-planning problems: Utah Simulation Model II. Utah Water Research Laboratory, Utah State University, Logan, Utah.
- Riley, J. Paul, J. M. Bagley, D. G. Chadwick, and E. K. Israelsen. 1967. The development of an electronic analog device for hydrologic investigations and conservation planning in the Sevier River Basin: Utah Simulation Model I. Utah Water Research Laboratory, Utah State University, Logan, Utah.
- Riley, J. Paul, and D. G. Chadwick. 1967. Application of an electronic analog computer to the problems of river basin hydrology. Utah Water Research Laboratory, Utah State University, Logan, Utah. December.
- Soil Conservation Service. Department of Agriculture. 1964. *Irrigation water requirements*. Technical Release No. 21, Washington, D.C. April. 61 p.
- Thorne, D. W., and H. W. Peterson. 1954. *Irrigated soils*. McGraw-Hill Book Company, Inc., New York. 392 p.
- U.S. Bureau of Reclamation. 1964. Central Utah Project initial phase. Bonneville unit. Definite plan report. Appendix B Water Supply. Vols. 1 and 2. Region 4, Salt Lake City, Utah. August.
- Van Bavel, C. H. M. 1966. Potential evaporation, the combination concept and its experimental verification. *Water Resources Research*, 2(3):455-467.
- Willardson, Lyman S., and Wendall L. Pope. 1963. Separation of evapotranspiration and deep percolation. *Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers* 89(IR3):77-88.

## APPENDIX A

### PARAMETER OPTIMIZATION MODEL

The Parameter Optimization Model was designed to be general in nature and not tied to a particular time sequence or specific units of input. The program presented is based on input and output for each month of the water year. The program is easily converted to a calendar year by changing the output titles and using data arranged on cards for the calendar year. The sample input is based on the water year so that the first month data on each card is for October.

The program was designed for use on the EAI 590 hybrid computer. The program presented is completely digital and contains logic statement peculiar to this computer. For example, the program makes use of sense switches which would have to be changed to "If" tests on many digital computers. The flow charts for this program indicate the intended logic of such controls.

A dummy scale area, ASCL, must be input when a subbasin does not contain agricultural area. The magnitude of ASCL must be chosen so the output will not overflow or underflow the output format. There must be at least one phreatophyte area within each subbasin.

Water which is imported to a subbasin can be treated as an import or a gaged inflow. When water is imported for direct application to agricultural or municipal and industrial use it should be handled as VAR(5) or VAR(6). Such water will be designated to those uses and will only enter the stream as return flow.

Water which is imported to the stream should be treated as a gage inflow to the subbasin. Irrigation or municipal and industrial water is exported by diverting the water in VAR(7) and VAR(8), respectively, and then exporting the water under VAR(11) and VAR(12).

The program has the ability to optimize the parameters or simulate the hydrology for a set of fixed parameters. This option is designated to aid the operator in parameter selection. The program is limited to a four-year study only by the dimensions of DVAR.

Cards outlined in the input data layout under I and II are total river basin data, the remainder of the cards apply to particular subbasins within the river basin. The sample input is for the Francis subbasin of the Provo River. Extra cards have been added which refer to the order outlined in the input data layout and should not be confused with actual input. The sample data and sample output are for the parameter calibration option. Not all of the VAR(L) data are shown due to the amount of card input for this subbasin.

The output from the program is in inches of water over the agricultural area. The sense switches allow the additional output of the results in acre feet.

The program listing and flow charts should be referred to simultaneously when questions arise about the logic within the program.

# INPUT DATA LAYOUT

## I. Basic Data

	Col	Identifier	
Card 1	1-40	BSNM	The river basin name
1	41-45	NVR	Number of variables; corresponds to number of VAR(L) in Table A-1
	46-50	NPR	Number of parameters; corresponds to number of PR(L) in Table A-1
	51-55	NYR	Number of year to be studied by the program
	56-60	INN	Input device indicator; i. e., tape or cards
	61-65	IOUT	Output device indicator; i. e., print or record on tape
	66-70	NITX	Maximum number of iterations in loop involving the calculation of soil moisture

Format (10A 4, 8I5)

## II. Total Basin Data

Card 1	1-4	OTL(1)	Output title for VAR(1)
	5-8	OTL(2)	Output title for VAR(2)
	.	.	.
	.	.	.
	.	.	.
	45-48	OTL(12)	Output title for VAR(12)
	49-52	OTL(13)	Output title for SIM(1)
	53-56	OTL(14)	Output title for SIM(2)
	.	.	.
	.	.	.
	.	.	.
	77-80	OTL(20)	Output title for SIM(8)

Format (20 A4)

Card 2	1-4	OTL(21)	Output title for SIM(9)
	5-8	OTL(22)	Output title for SIM(10)
	.	.	.
	.	.	.
	.	.	.
	21-24	OTL(26)	Output title for SIM(14)
	25-28	OTL(27)	Output title for VAR(13)
	29-32	OTL(28)	Output title for SIM(15)

Format (20 A4)

The abbreviations used in the input and corresponding output refer to the definitions of the VAR(L)'s

and SIM(L)'s given in Table A-1 and Table A-2, respectively. The plus and minus sign on the abbreviations indicate gains or losses to the system.

Card 3	1-5	DLH(1)	Fraction daylight hours for month 1
	6-10	DLH(2)	Fraction daylight hours for month 2
	.	.	.
	.	.	.
	.	.	.
	56-60	DLH(12)	Fraction daylight hours for month 12
	61-65	NCR	Number of crop evapotranspirations to be simulated, see Table A-2
	66-70	NPH	Number of phreatophyte evapotranspirations to be simulated, see Table A-2
	71-75	INPH	Indicates which objective function to use (0 or 1)

0 - will use Equation 4.3 and emphasize low flows  
1 - will use Equation 4.2 and emphasize high flows

Format (12 F5.3, 4I5)

Card 4	1-10		Crop identification
	11-15	CCR(1,1)	$k_c$ for crop 1 month 1
	16-20	CCR(1,2)	$k_c$ for crop 1 month 2
	.	.	.
	.	.	.
	.	.	.
	66-70	CCR(1,12)	$k_c$ for crop 1 month 12

Format (10X, 12F5.2)

This format is repeated for Crop 2, 3, ... NCR. (For  $k_c$  see Equation 3.18.)

Card 5	1-10		Phreatophyte identification
	11-15	CPH(1,1)	$k_c$ for phreatophyte 1 month 1
	16-20	CPH(1,2)	$k_c$ for phreatophyte 1 month 2
	.	.	.
	.	.	.
	.	.	.
	66-70	CPH(1,12)	$k_c$ for phreatophyte 1 month 2

Format (10X, 12F5.2)  
This format is repeated for phreatophyte 2, 3, ... NPH.

### III. Choose to Simulate the Hydrology or Optimize the Parameters

Card 1 4 IDOP 0 - Program will simulate the hydrology for a single set of parameters for NYR years  
1 - Program will optimize the parameters based on NYR years of data

Format (20I4)

### IV. Subbasin Data

Card 1 1-20 SBNM Subbasin name  
1 21-30 AGAG Gaged area of the subbasin in acres (does not include agricultural area)  
31-40 AUNG Ungaged area of the subbasin in acres (does not include agricultural area)  
45 IDCR 0 - Indicates no crop land within subbasin  
1 - Indicates crop land within subbasin  
46-50 ADMS Tolerance desired in the calculation of soil moisture. ADMS is in inches of water  
51-60 ACOR Drainage area of the stream used for ungaged flow correlation, in acres  
61-65 TMP1 Temperature adjustment in degrees Fahrenheit used in snowmelt calculation for the ungaged area; a positive number for decrease (see Equation 3.6)

Format (5A4, 2F10.0, I5, F5.3, F10.0, F5.1)

If IDCR = 0, Skip Card 2

Card 2 1-10 ACR(1) Acres of crop 1  
11-20 ACR(2) Acres of crop 2  
.  
.  
.  
ACR(NCR) Acres of crop NCR  
10 col TACR Total crop acres (sum of ACR's)

Format (8F10.0)

Card 3 1-10 APH(1) Acres of phreatophyte 1  
11-20 APH(2) Acres of phreatophyte 2  
.  
.  
.  
APH(NPH) Acres of phreatophyte NPH  
10 col TAPH Total phreatophyte acres (sum of APH's)  
10 col ASCL A dummy scaling area for subbasin with no crop area (necessary when IDCR = 0)

Format (8F10.0)

If IDOP = 0 input model parameter cards here (Card 2 of VI).

Card 4 1-4 NST(1) Number of stations of VAR(1)  
5-8 NST(2) Number of stations of VAR(2)  
.  
.  
.  
NST(NVR) Number of stations of VAR(NVR)

Format (20I4)

VAR's given in Table A-1

Card 5 21-30 CONV(3) Conversion factor for VAR(3)  
31-40 CONV(4) Conversion factor for VAR(4)  
.  
.  
.  
CONV(NVR) Conversion factor for VAR(NVR)  
10 col CAF Conversion of acre-feet to inches of water over the agricultural acres or scaling area

Format (8F10.6)

where:

CONV(L) Converts the units of VAR(L) to inches of water over the agricultural area. If VAR(L) is in acre-feet, CONV(L) = CAF

CAF = 12/TACR if IDCR = 1

CAF = 12/ASCL if IDCR = 0

Card 6 1-5 CWT(1,1) Weight factor to apply to temperature station 1  
6-10 CWT(1,2) Weight factor to apply to temperature station 2  
.  
.  
.  
CWT(1, NST[1]) Weight factor to apply to temperature station NST(1)

Format (16F5.3)

Card	1-5	CWT(2, 1)	Weight factor to apply to precipitation station 1
7	6-10	CWT(2, 2)	Weight factor to apply to precipitation station 2
	.	.	.
	.	.	.
	.	.	.
	CWT(2, NST[2])	Weight factor to apply to precipitation station NST(2)	

Format (16F5.3)

For this study CWT(2,N's) come from Equation 3.2, but the program allows for any weighting factor to be input.

#### V. Observed Data

Card	1-5	LYRO	Starting year of data
1	6-10	SNOW	Initial snow storage in inches of water

Format (I5,F5.0)

Card	9-14	CORS(1, 1)	Correlation streamflow year 1 month 1
2	15-20	CORS(1, 2)	Correlation streamflow year 1 month 2
	.	.	.
	.	.	.
	.	.	.
	75-80	CORS(1, 12)	Correlation streamflow year 1 month 12

Format (8X,-3P12F6.1)

This format is repeated for year 2, 3, ... NYR. The input format is for CORS in thousands acre-feet.

Card	4	IFMT(1)	Read format indicator for VAR(1)
3	8	IFMT(2)	Read format indicator for VAR(2)
	.	.	.
	.	.	.
	.	.	.
	4 (NVR)	IFMT (NVR)	Read format indicator for VAR(NVR)

Format (20I4)

Input a 1 to 5 depending on which format on the next card, Card 4 is appropriate. (See flow chart for IPOD)

Card	1-16	FMT1	A specific input format
4	17-32	FMT2	A specific input format
	.	.	.
	.	.	.
	.	.	.
	65-80	FMT5	A specific input format
		Format (5[4A4])	

Card  
5

The VAR(L) of Table A-1 are input at this point, according to the formats specified on Cards 3 and 4. For example, with IFMT(2) = 3 the program will read all stations of VAR(2) according to FMT3. Card 4 of IV specifies the number of stations for each variable.

Each card must contain twelve monthly values and all stations of each VAR(L) must be punched with the same format and in the same units.

Starting with VAR(1) the data for year 1 to NYR are input in ascending yearly order for station 1. This is followed by NYR years of data for station 2, 3, ... NST(1). The ordering of the stations is not important because they are summed to form DVAR. Data for VAR(2), VAR(3), ..., VAR(NVR) are then input in the same manner.

The VAR(L) data are input by year, station, then variable. If any NST(L) = 0, that variable is skipped. The sample input should make the ordering clear.

If IDOP = 0, do not input remaining cards

#### VI. Parameter Input

Card	1-4	NPHS	Number of phases of the optimization to be run (generally 3 or 4)
1			

Format (20I4)

Card	1-5	PRO(1)	Initial value of PR(1)
2	6-10	PRO(2)	Initial value of PR(2)
	.	.	.
	.	.	.
	.	.	.
		PRO(NPR)	Initial value of PR(NPR)

Format (16F5.2)

Card	1-4	NLV(1)	Number of increments for PR(1)
3	5-8	NLV(2)	Number of increments for PR(2)
	.	.	.
	.	.	.
	.	.	.
		NLV(NPR)	Number of increments for PR(NPR)

Format (20I4)

If NLV(L) = 0 or 1, no Card 4 is to be input for that parameter and it is therefore not optimized.

Card One card for each parameter with NLV(L) > 1, 4 input in ascending order.

6-10	PRL(L)	Low level of PR(L)
7-15	PRH(L)	High level of PR(L)

Format (5X,2F5.2)

The step size for each parameter during optimization is calculated as:

$$\frac{PRH(L) - PRL(L)}{NLV(L)}$$

Table A1. Definition of variables and parameters.

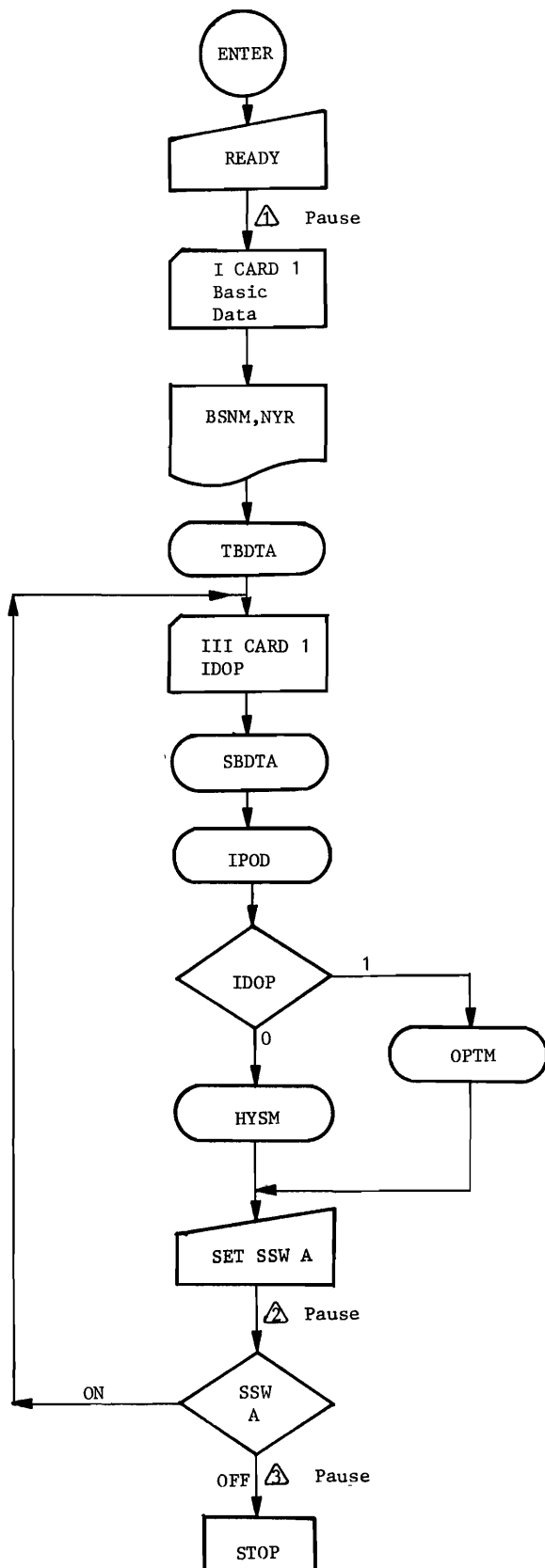
L	Variables	Parameters	Equation
1	Mean monthly temperature	Snowfall temperature	Chapter 3 Precipitation Sect.
2	Total monthly precipitation	Snowmelt temperature	3.3 $T_m$
3	Gaged surface inflow	Soil moisture holding capacity	3.27 $M_{cs}$
4	Gaged or estimated groundwater inflow	Critical soil moisture	3.27 $M_{es}$
5	Irrigation Import	Ungaged stream correlation coefficient	3.7 $K_1$
6	M & I Import	Subsurface storage coefficient	3.33 $K_{ss}$
7	Irrigation surface flow diversions	Groundwater storage coefficient	3.35 $K_g$
8	M & I surface flow diversions	Snowmelt coefficient	3.4 $K_s$
9	Irrigation pumpage	Consumptive use coefficient	3.25 $K_u$
10	M & I pumpage	Irrigation efficiency	3.13 $Eff$
11	Irrigation Export	M & I efficiency	3.16 $Eff_{mi}$
12	M & I export	Coefficient of rain plus snowmelt for ungaged flow	3.7 $K_2$
13	Gaged surface outflow	Threshold for surface runoff	3.7 $K_3$
14	Minimum stream flow	Base flow coefficient	3.36 $K_{bf}$
15		Infiltration coefficient	3.33 $C_i$
16		Initial soil moisture	3.28 $M_s(0)$
17		Initial base and groundwater outflow	3.35 $Q_{gao}$
18		Initial watershed recharge	3.32 $Q_{sg}$

Table A2. Definition of variables and parameters.

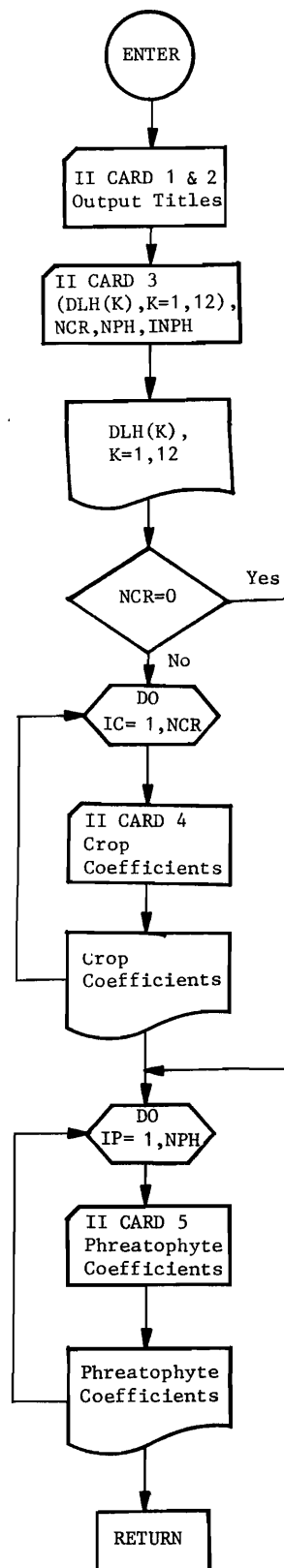
L	Simulated Quantities	Equation
1	Not used	
2	Snow storage	3.5 $W_s(t)$
3	Snowmelt rate	3.5 $W_s(0) - W_s(1)$
4	Phreatophyte evapotranspiration	3.25 $ET_{pr}$
5	Crop evapotranspiration	3.26, 27 $ET_r$
6	Soil moisture	3.19 $M_s(t)$
7	Deep percolation	3.29, 30 $DP_r$
8	Ungaged surface inflow	3.7 $Q_{ug}$
9	Return flow	3.15, 16 $Q_{ri} + Q_{rmi}$
10	Base flow	3.36 $Q_{bf}$
11	Water deficit	$SIM(14) - VAR(14)$
12	Total outflow	3.39 $Q_{to}$
13	Groundwater outflow	3.37 $Q_{go}$
14	Surface outflow	3.38 $Q_{so}$
15	Deviation from observed surface outflow	$VAR(13) - SIM(14)$

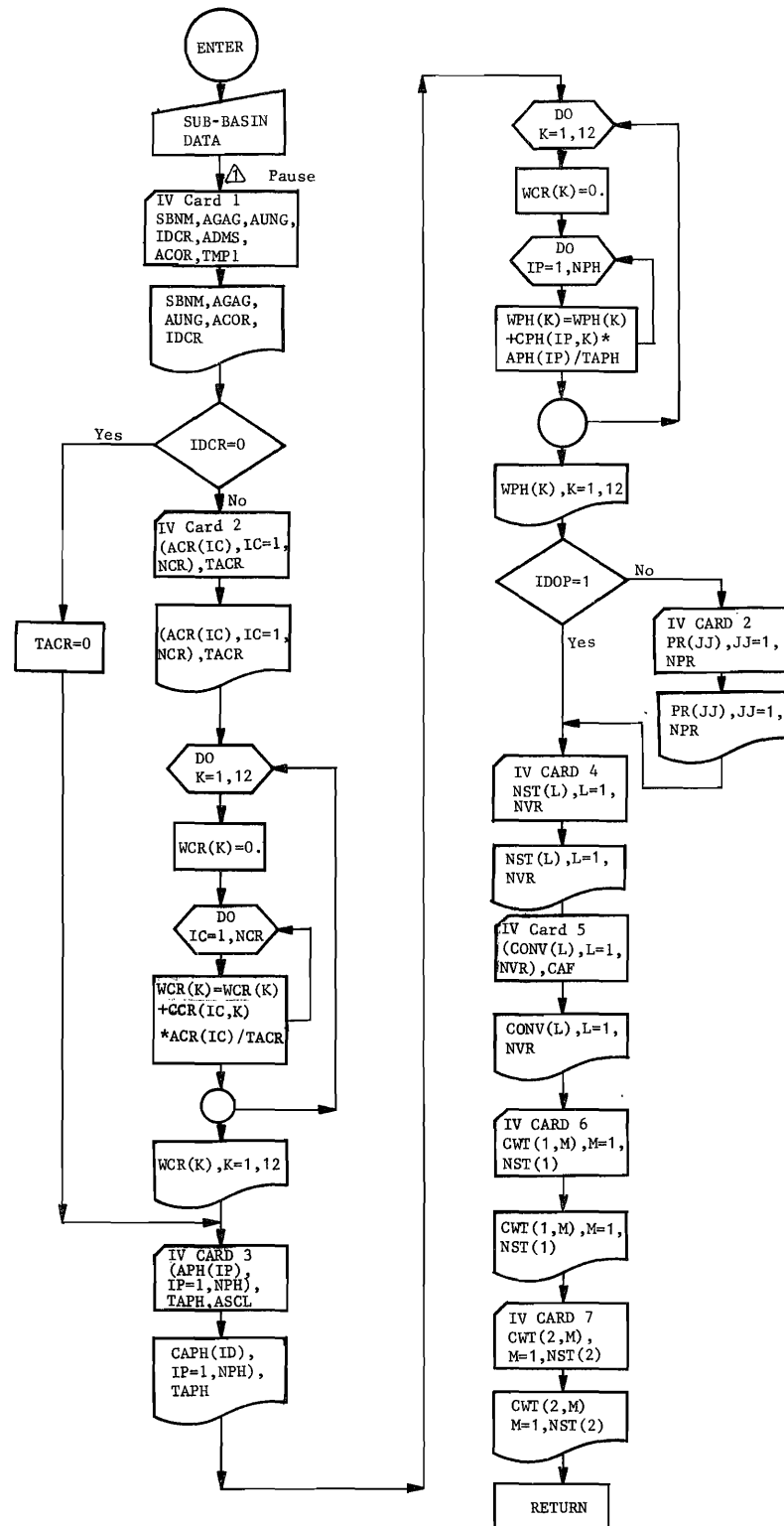


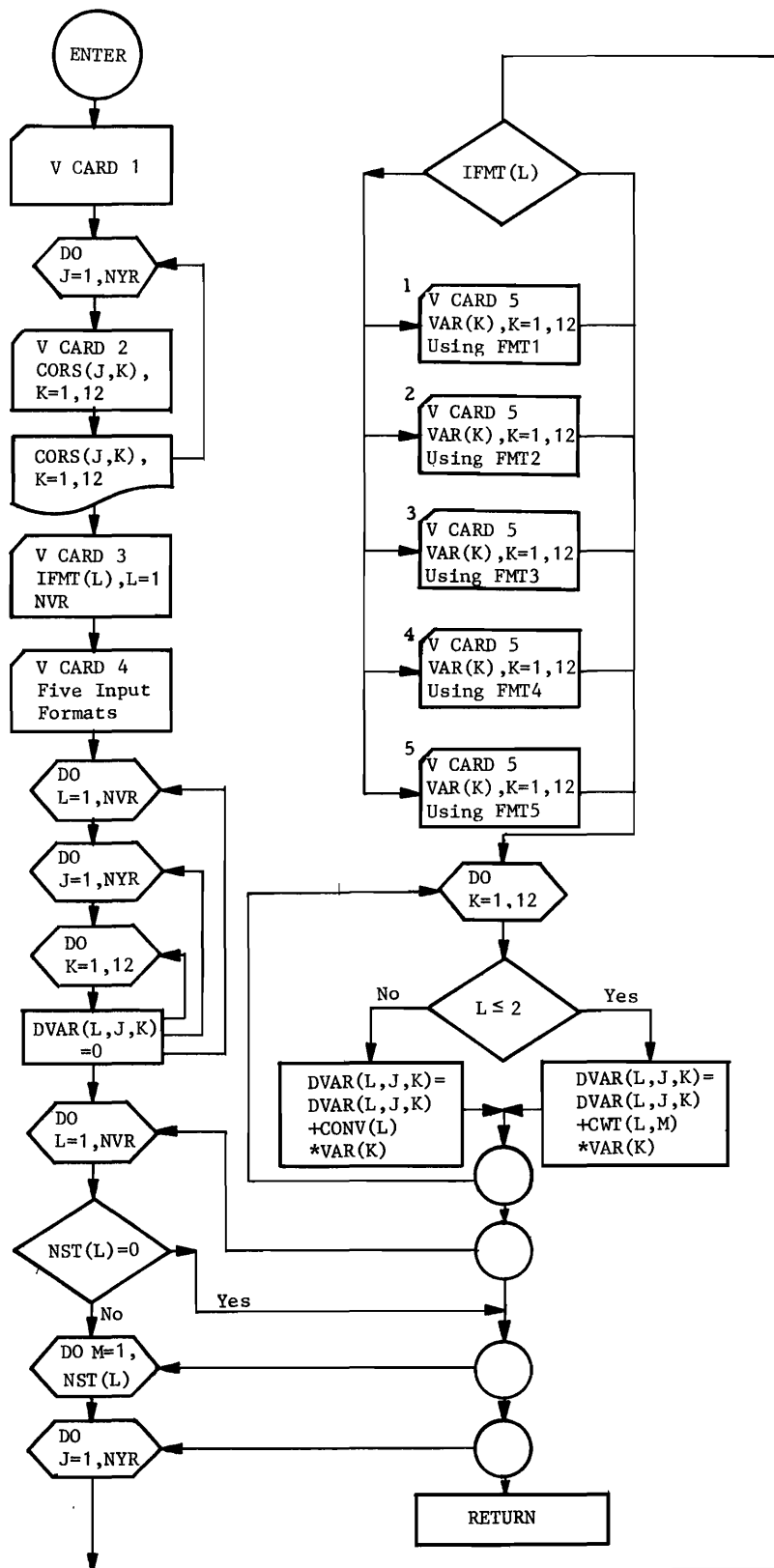
# MAIN PROGRAM

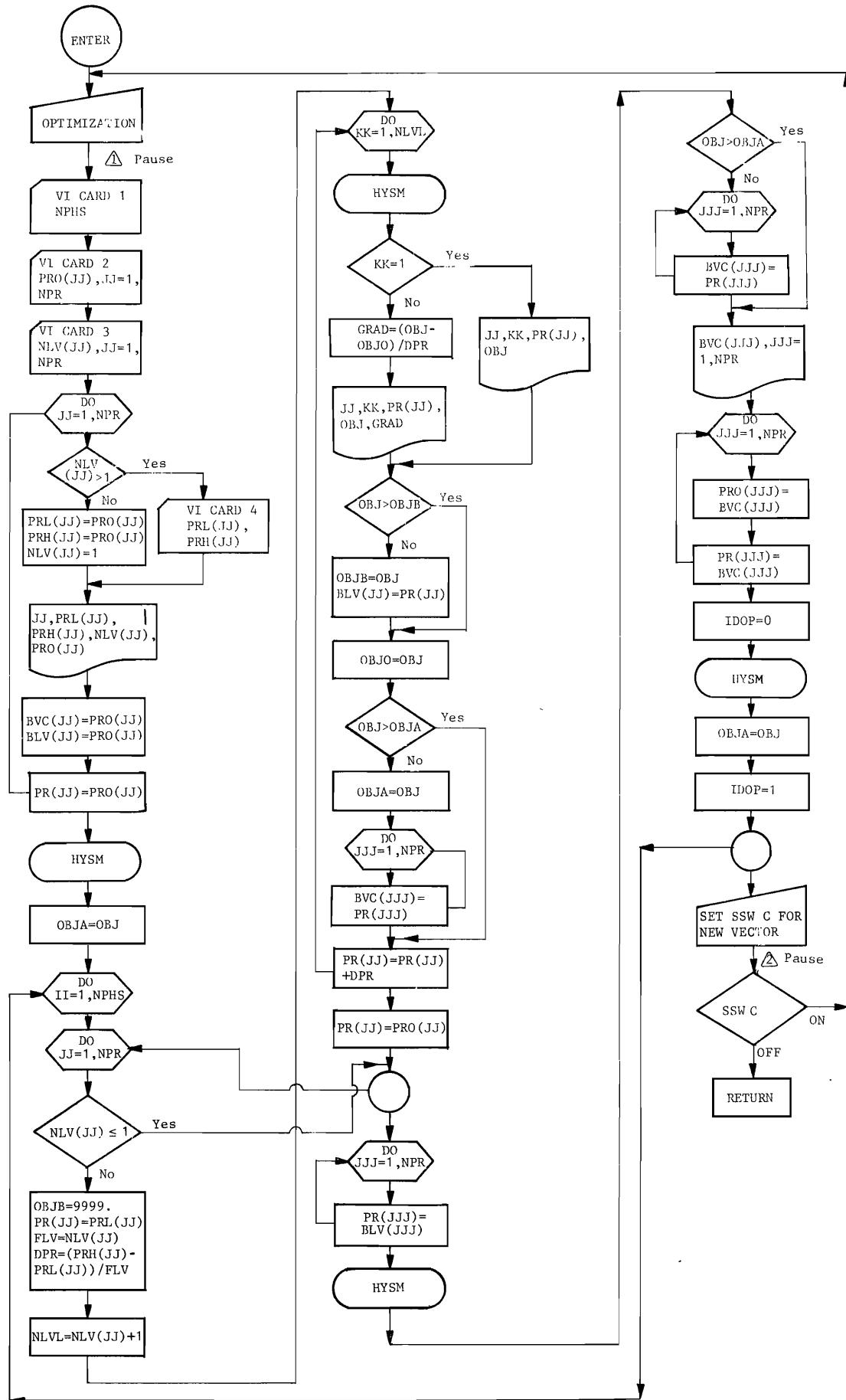


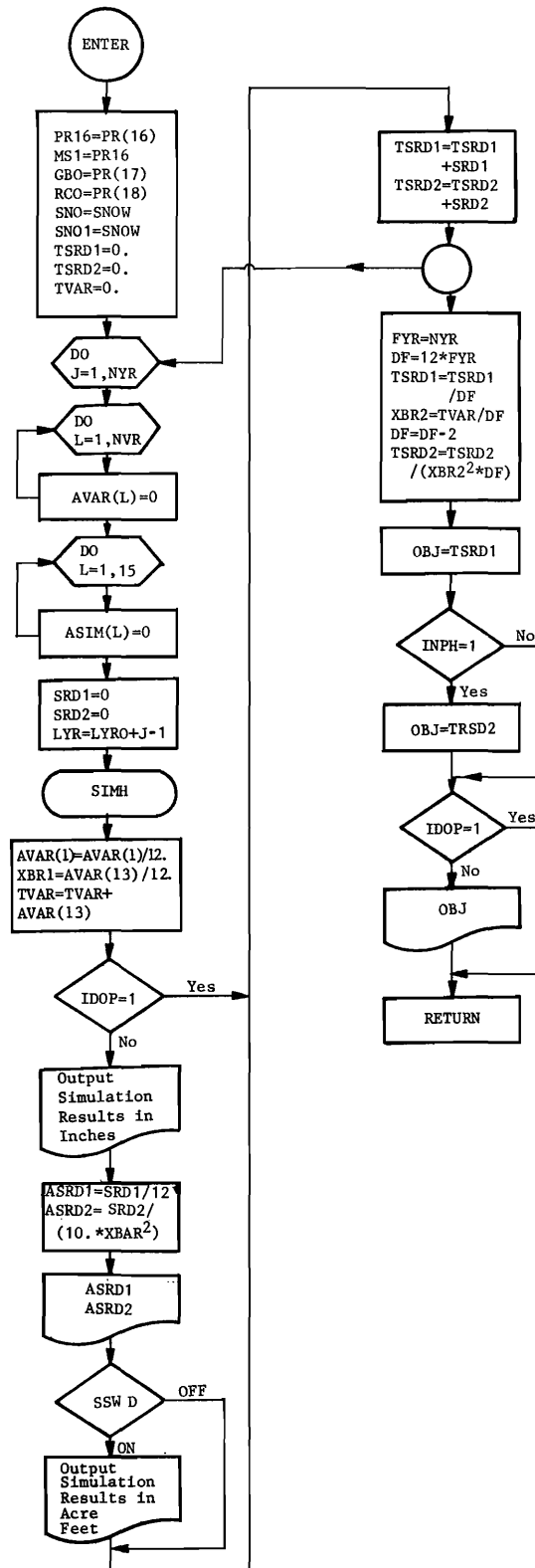
# TBDTA

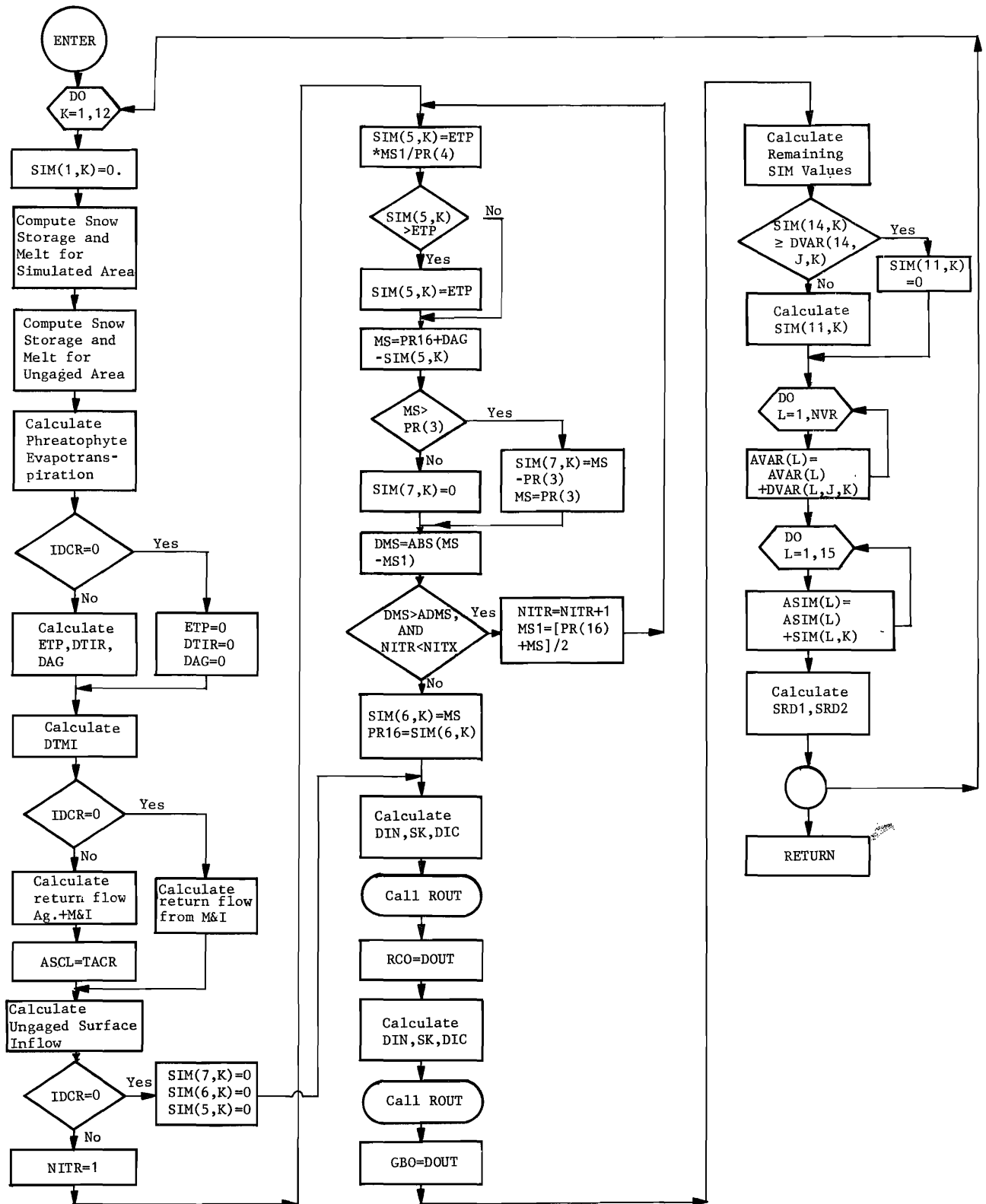












# PARAMETER OPTIMIZATION PROGRAM LISTING

```

C   PARAMETER OPTIMIZATION FOR HYDROLOGIC SIMULATION MODEL --MPOP
COMMON/BLK1/      ASIM(15),AVAR(14),CCR(14,12),CONV(14),
1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
3PRO(18),          SBNM(5),SIM(15,12),VAR(12),
4WCR(12),WPH(12)
COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,G80,
1IDCR,      IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
2OBJ,RC0,SK,SNO,SNOW,SN01,SNW1,SRD1,SRD2,      TACR,TAPH,TMP1,PR16
3,INPH
REAL MS1
DIMENSION BSNM(10)
1 TYPE 200
200 FORMAT(5HREADY/)
OCT 25000
C   INPUT BASIC DATA
READ(6,300) (BSNM(I),I=1,10),NVR,NPR,NYR,INN,IOUT,NITX
300 FORMAT(10A4,8I5)
WRITE(IOUT,201) (BSNM(I),I=1,10),NYR
201 FORMAT(1H1,10A4,5X,5HNYR #,I2//)
CALL TBDTA
2 READ(INN,301) IDOP
301 FORMAT(20I4)
C   INPUT SUB-BASIN DATA
CALL SBDTA
CALL IP0D
IF(IDOP.EQ.1) GO TO 3
CALL HYSM(0)
J      .4
3 CALL OPTM
4 TYPE 1202
1202 FORMAT(10H SET SUB A/)
OCT 25000
C   IF SUB A ON, REPEAT SUB-BASIN OPERATION
OCT 023000
J      .6
J      .2
6 OCT 25000
STOP
END
C   SUBROUTINE FOR TOTAL BASIN DATA
SUBROUTINE TBDTA
COMMON/BLK1/      ASIM(15),AVAR(14),CCR(14,12),CONV(14),
1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
3PRO(18),          SBNM(5),SIM(15,12),VAR(12),
4WCR(12),WPH(12)
COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,G80,
1IDCR,      IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
2OBJ,RC0,SK,SNO,SNOW,SN01,SNW1,SRD1,SRD2,      TACR,TAPH,TMP1,PR16
3,INPH
REAL MS1
READ OUTPUT TITLES
READ(INN,302) (OTL(II),II=1,28)
302 FORMAT(20A4)
C   INPUT DAY-LIGHT HOURS AND NUMBER OF CROPS AND PHREATOPHYTES
READ(INN,303) (DLH(K),K=1,12),NCR,NPH,INPH
303 FORMAT(12F5,3,4I5)
WRITE(IOUT,203) (DLH(K),K=1,12)
203 FORMAT(25H FRACTION DAY-LIGHT HOURS/12F6,3//)
IF(NCR.EQ.0) GO TO 9
C   INPUT CROP COEFFICIENTS
WRITE(IOUT,204)
204 FORMAT(10H CROP COEFFICIENTS)
DO 8 IC=1,NCR
READ(INN,304) (CCR(IC,K),K=1,12)
304 FORMAT(10X,12F5,2)
8 WRITE(IOUT,205) (CCR(IC,K),K=1,12)
205 FORMAT(12F6,2)

```

```

C   INPUT PHREATOPHYTE COEFFICIENT
9 WRITE(IOUT,206)
206 FORMAT(/26H PHREATOPHYTE COEFFICIENTS)
DO 10 IP=1,NPH
READ(INN,304) (CPH(IP,K),K=1,12)
10 WRITE(IOUT,205) (CPH(IP,K),K=1,12)
RETURN
END
C   SUBROUTINE FOR SUB-BASIN DATA
SUBROUTINE SBDTA
COMMON/BLK1/      ASIM(15),AVAR(14),CCR(14,12),CONV(14),
1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
3PRO(18),          SBNM(5),SIM(15,12),VAR(12),
4WCR(12),WPH(12)
COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,G80,
1IDCR,      IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
2OBJ,RC0,SK,SNO,SNOW,SN01,SNW1,SRD1,SRD2,      TACR,TAPH,TMP1,PR16
3,INPH
REAL MS1
DIMENSION ACR(14),APH(7)
TYPE 207
207 FORMAT(15H SUB-BASIN DATA/)
READ(INN,305) (SBNM(IB),IB=1,5),AGAG,AUNG,IDCR,      ADMS,ACOR,TMP1
305 FORMAT(5A4,2F10.0, 15,F5,3,F10.0,F5,1)
WRITE(IOUT,208) (SBNM(IB),IB=1,5),AGAG,AUNG,ACOR,IDCR
208 FORMAT(1H1,5A4,2X6HAGAG =,F10.0,2X6HAUNG =,F10.0,2X6HACOR =,F10.0
1,2X6HIDCR =,I2)
IF(IDCR.EQ.0) GO TO 12
READ(INN,306) (ACR(IC),IC=1,NCR),TACR
306 FORMAT(8F10,0)
WRITE(IOUT,209) (ACR(IC),IC=1,NCR),TACR
209 FORMAT(11H CROP AREAS/(8F10,0))
C   COMPUTE WEIGHTED CROP COEFFICIENT
DO 11 K=1,12
WCR(K)=0.
DO 11 IC=1,NCR
11 WCR(K)=WCR(K)+CCR(IC,K)*ACR(IC)/TACR
WRITE(IOUT,210) (WCR(K),K=1,12)
210 FORMAT(/26H WEIGHTED CROP COEFFICIENT/12F6,2)
J      .1013
12 TACR=0.
1013 READ(INN,306) (APH(IP),IP=1,NPH),TAPH,ASCL
WRITE(IOUT,211) (APH(IP),IP=1,NPH),TAPH
211 FORMAT(/19H PHREATOPHYTE AREAS/8F10,0)
C   COMPUTE WEIGHTED PHREATOPHYTE COEFFICIENT
DO 13 K=1,12
WPH(K)=0.
DO 13 IP=1,NPH
13 WPH(K)=WPH(K)+CPH(IP,K)*APH(IP)/TAPH
WRITE(IOUT,212) (WPH(K),K=1,12)
212 FORMAT(/34H WEIGHTED PHREATOPHYTE COEFFICIENT/12F6,2)
IF(IDOP.EQ.1) GO TO 15
C   INPUT MODEL PARAMETERS
READ(INN,1306) (PR(JJ),JJ=1,NPR)
1306 FORMAT(16F5,2)
WRITE(IOUT,213) (PR(JJ),JJ=1,NPR)
213 FORMAT(/17H PARAMETER VALUES/(8F5,2))
15 READ(INN,3306) (NST(L),L=1,NVR)
3306 FORMAT(20I4)
WRITE(IOUT,215) (NST(L),L=1,NVR)
215 FORMAT(/37H NUMBER OF STATIONS FOR EACH VARIABLE/16I5)
READ(INN,307) (CONV(L),L=1,NVR),CAF
307 FORMAT(8F10,0)
WRITE(IOUT,216) (CONV(L),L=1,NVR)
216 FORMAT(/19H CONVERSION FACTORS/(8F10,0))
C   INPUT STATION WEIGHT FOR TEMPERATURE AND PRECIPITATION
NST1=NST(1)
READ(INN,1307) (CWT(1,M),M=1,NST1)
1307 FORMAT(16F5,3)
WRITE(IOUT,217) (CWT(1,M),M=1,NST1)
217 FORMAT(/32H STATION WEIGHTS FOR TEMPERATURE/1X,12F5,3)
NST2=NST(2)

```

```

      READ(INN,1307) (CWT(2,M),M=1,NST2)
      WRITE(OUT,218) (CWT(2,M),M=1,NST2)
218 FORMAT(/34H STATION WEIGHTS FOR PRECIPITATION/1X,12F5.3)
      RETURN
      END
C     SUBROUTINE TO INPUT OBSERVED DATA
      SUBROUTINE IPOD
      COMMON/BLK1/      ASIM(15),AVAR(14),CCR(14,12),CONV(14),
      1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
      2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),DTL(20),PR(18),
      3PRO(18),          SBNM(5),SIM(15,12),VAR(12),
      4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOU,GB0,
      1IDCR,          IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
      2OBJ,RC0,SK,SNO,SNOW,SN01,SNW1,SRD1,SRD2,      TACR,TAPH,TMP1,PR16
      3,INPH
      REAL MS1
      READ(INN,309) LYRO,SNOW
309 FORMAT(15,F5.0)
C
C     INPUT CORRELATION STREAMFLOW
      WRITE(OUT,200)
200 FORMAT(/17H CORR. STREAMFLOW)
      DO 31 J=1,NVR
      READ(INN,100) (CORS(J,K),K=1,12)
      WRITE(OUT,201) (CORS(J,K),K=1,12)
100 FORMAT(8X,-3P12F6.1)
201 FORMAT(1X,-3P12F6.1)
C
C     INPUT DATA FORMAT INDICATOR AND FORMAT
      READ(INN,1309) (IFMT(L),L=1,NVR)
1309 FORMAT(20I4)
      READ(INN,310) (FMT1(L1),L1=1,4), (FMT2(L2),L2=1,4), (FMT3(L3),L3=1,4),
      1), (FMT4(L4),L4=1,4), (FMT5(L5),L5=1,4)
310 FORMAT(5(4A4))
      DO 32 L=1,NVR
      DO 32 J=1,NVR
      DO 32 K=1,12
32 DVAR(L,J,K)=0.
      DO 40 L=1,NVR
      NSTN=NST(L)
      IF(NSTN.EQ.0) GO TO 40
      LFMT=IFMT(L)
      DO 40 M=1,NSTN
      DO 40 J=1,NVR
      GO TO (33,34,35,36,37),LFMT
33 READ(INN,FMT1) (VAR(K),K=1,12)
      J ,38
34 READ(INN,FMT2) (VAR(K),K=1,12)
      J ,38
35 READ(INN,FMT3) (VAR(K),K=1,12)
      J ,38
36 READ(INN,FMT4) (VAR(K),K=1,12)
      J ,38
37 READ(INN,FMT5) (VAR(K),K=1,12)
C     COMPUTE AVERAGE OR TOTAL MONTHLY DATA
38 DO 40 K=1,12
      IF(L.E.2) GO TO 39
      DVAR(L,J,K)=DVAR(L,J,K)+CONV(L)*VAR(K)
      J ,40
39 DVAR(L,J,K)=DVAR(L,J,K)+CWT(L,M)*VAR(K)
40 CONTINUE
      RETURN
      END
C     PARAMETER OPTIMIZATION SUBROUTINE
      SUBROUTINE OPTM
      COMMON/BLK1/      ASIM(15),AVAR(14),CCR(14,12),CONV(14),
      1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
      2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),DTL(20),PR(18),
      3PRO(18),          SBNM(5),SIM(15,12),VAR(12),
      4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOU,GB0,
      1IDCR,          IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR,      NVR,NYR,
      2OBJ,RC0,SK,SNO,SNOW,SN01,SNW1,SRD1,SRD2,      TACR,TAPH,TMP1,PR16
      3,INPH
      REAL MS1
      READ(INN,1307) (CWT(2,M),M=1,NST2)
      WRITE(OUT,218) (CWT(2,M),M=1,NST2)
218 FORMAT(/34H STATION WEIGHTS FOR PRECIPITATION/1X,12F5.3)
      RETURN
      END
      DIMENSION BLV(18),BVC(18),NLV(18),PRH(18),PRL(18)
      TYPE 219
219 FORMAT(13H OPTIMIZATION/)
      OCT 25000
C     ASSIGN NO. OF PHASES
      READ(INN,2307) NPHS
C     INPUT INITIAL VECTOR
      READ(INN,1307) (PRO(JJ),JJ=1,NPR)
1307 FORMAT(18F5.2)
      WRITE(OUT,220) (SBNM(IB),IB=1,5)
220 FORMAT(1H1,5A4//)
C     INPUT OPTIMIZATION INDICATOR
      READ(INN,2307) (NLV(JJ),JJ=1,NPR)
2307 FORMAT(20I4)
      WRITE(OUT,221)
221 FORMAT(80H PARAMETER RANGE,NO. OF INCREMENTS AND INITIAL VECTOR//
      13X2HJJ,5X3HPRL,5X3HPRH,3X3HNLV,6X3HPRO)
C     INPUT PARAMETER RANGE
      DO 19 JJ=1,NPR
      IF (NLV(JJ).GT.1) GO TO 17
      PRL(JJ)=PRO(JJ)
      PRH(JJ)=PRO(JJ)
      NLV(JJ)=1
      J ,18
17 READ(INN,308) PRL(JJ),PRH(JJ)
308 FORMAT(5X,2F5.2)
18 WRITE(OUT,222) JJ,PRL(JJ),PRH(JJ),NLV(JJ),PRO(JJ)
222 FORMAT(15,2F8.2,15,F10.2)
C     INITIALIZE OPTIMAL VECTOR
      BVC(JJ)=PRO(JJ)
      BLV(JJ)=PRO(JJ)
C     SET PARAMETER TO INITIAL VALUE
19 PR(JJ)=PRO(JJ)
C     INITIALIZE OBJECTIVE FUNCTION
      CALL HYSM(0)
      OBJA=OBJJ
C     REPEAT OPTIMIZATION PROCEDURE FOR EACH PHASE
      DO 30 II=1,NPHS
      WRITE(OUT,223) II
223 FORMAT(1H1,5HPHASE,I3//10H PAR LVL,3X,7HPAR. V.,7X,3H0BJ,16X,4HG
      1RAD)
C     OPTIMIZE EACH PARAMETER
      DO 25 JJ=1,NPR
      IF (NLV(JJ).LE.1) GO TO 25
      OBJB=9999.
      PR(JJ)=PRL(JJ)
      FLV=NLV(JJ)
      DPR=(PRH(JJ)-PRL(JJ))/FLV
C     SEARCH FOR EVERY LEVEL
      NLVL=NLV(JJ)+1
      DO 24 KK=1,NLVL
      CALL HYSM (JJ)
      IF(KK.EQ.1) GO TO 20
      GRAD=(OBJJ-OBJB)/DPR
      WRITE(OUT,224) JJ,KK,PR(JJ),OBJJ,GRAD
224 FORMAT(215,F10.2,F10.5,5X,F15.8)
      J ,21
20 WRITE(OUT,224) JJ,KK,PR(JJ),OBJJ
21 IF(OBJJ.GT.OBJB) GO TO 22
      OBJB=OBJJ
      BLV(JJ)=PR(JJ)
22 OBJJ=OBJJ
      IF(OBJJ.GT.OBJA) GO TO 24
      OBJA=OBJJ
      DO 23 JJJ=1,NPR
      BVC(JJJ)=PR(JJJ)
23 BVC(JJJ)=PR(JJJ)
24 PR(JJJ)=PR(JJJ)+DPR
      PR(JJJ)=PRO(JJJ)
25 CONTINUE
      DO 26 JJJ=1,NPR
      PR(JJJ)=BLV(JJJ)
26 PR(JJJ)=BLV(JJJ)

```



```

      CALL HYSM (0)
      IF(OBJ,GT,OBJA) GO TO 28
      DO 27 JJJ=1,NPR
27   BVC(JJJ)=PR(JJJ)
28   WRITE(IOUT,225) (BVC(JJJ),JJJ=1,NPR)
225  FORMAT(1H1,34HTHE OPTIMAL FACTORS ARE AS FOLLOWS/(8F8,2))
      DO 29 JJJ=1,NPR
      PRO(JJJ)=BVC(JJJ)
29   PR(JJJ)=BVC(JJJ)
C    SET IDOP TO 0 TO PRINT OUT SIMULATION RESULTS
      IDOP=0
      CALL HYSM (0)
      OBJA=OBJ
C    SET IDOP BACK TO 1 TO PROCEED FOR ANOTHER PHASE OF OPTIMIZATION
      IDOP=1
30  CONTINUE
      TYPE 226
226  FORMAT(25H SET SSW C FOR NEW VECTOR/)
      OCT 25000
      OCT 023400
      J .31
      J .16
31  RETURN
      END
C    HYDROLOGIC SIMULATION SUBROUTINE
      SUBROUTINE HYSM (JJ)
      COMMON/BLK1/ ASIM(15),AVAR(14),CCR(14,12),CONV(14),
1COR3(4,12),CPH(5,12),CMT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(20),PR(10),
3PRO(10),
4WCR(12),WPH(12)
      COMMON/BLK3/ACOR,ADM8,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,G80,
1IDCR, IDOP,INN,IOUT,LYRO,M81,NCR,NITX,NPH,NPR, NVR,NYR,
2OBJ,RC0,SK,SNO,SNOW,SNO1,SNW1,SRD1,SRD2, TACR,TAPH,TMP1,PR10
3,INPH
      REAL M81
      PR10=PR(16)
      M81=PR16
      G80=PR(17)
      RC0=PR(18)
      SNO=SNOW
      SNO1=SNOW
      TSRD1=0.
      TSRD2=0.
      TVAR=0.
C    REPEAT SIMULATION PROCEDURE FOR EACH YEAR
      DO 86 J=1,NYR
      DO 1068 L=1,NVR
1068  AVAR(L)=0.
      DO 2068 L=1,15
2068  ASIM(L)=0.
      SRD1=0.
      SRD2=0.
      LYR=LYRO+J-1
C    SIMULATE MONTHLY HYDROLOGY
      CALL SIMH(J)
      AVAR(1)=AVAR(1)/12.
C    ANNUAL STANDARD DEVIATION AND COEFFICIENT OF VARIATION
      XBR1=(AVAR(13)/12.)
      TVAR=TVAR+AVAR(13)
      IF (IDOP.EQ.1) GO TO 85
C    OUT-PUT SIMULATION RESULT
      WRITE(IOUT,228) (SBNM(18),18=1,5),LYR
228  FORMAT(1H1,5A4,I5/)
      WRITE(IOUT,229)
229  FORMAT(70H VAR OCT NOV DEC JAN
1 FEB MAR)
      DO 69 L=1,12
69   WRITE(IOUT,230) OTL(L),(DVAR(L,J,K),K=1,6)
230  FORMAT(6X,A4,7F10.3)
      DO 70 L=2,14

```

```

      L1=L+12
70  WRITE(IOUT,230) OTL(L1),(SIM(L,K),K=1,6)
      WRITE(IOUT,230) OTL(27),(DVAR(13,J,K),K=1,6)
      WRITE(IOUT,230) OTL(28),(SIM(15,K),K=1,6)
      WRITE(IOUT,231)
231  FORMAT(/80H VAR APR MAY JUN JUL
1 AUG SEPT ANN)
      DO 71 L=1,12
71  WRITE(IOUT,230) OTL(L),(DVAR(L,J,K),K=7,12),AVAR(L)
      DO 72 L=2,14
      L1=L+12
72  WRITE(IOUT,230) OTL(L1),(SIM(L,K),K=7,12),ASIM(L)
      WRITE(IOUT,230) OTL(27),(DVAR(13,J,K),K=7,12),AVAR(13)
      WRITE(IOUT,230) OTL(28),(SIM(15,K),K=7,12),ASIM(15)
      ASRD1=SRD1/12.
      ASRD2=SRD2/(10.*XBR1+XBR1)
      WRITE(IOUT,1235) ASRD1,ASRD2
1235  FORMAT(/8H ASRD1 =,F10.5,5X,8H ASRD2 =,F10.5)
C    IF SSW D ON, OUT-PUT ACRE-FEET
      OCT 023420
      J .85
C    CONVERT QUANTITIES TO ACRE FEET
      DO 73 L=2,13
      AVAR(L)=AVAR(L)/CAF
      DO 73 K=1,12
73  DVAR(L,J,K)=DVAR(L,J,K)/CAF
      DO 74 L=1,15
      ASIM(L)=ASIM(L)/CAF
      DO 74 K=1,12
74  SIM(L,K)=SIM(L,K)/CAF
      WRITE(IOUT,233) (SBNM(18),18=1,5),LYR
233  FORMAT(1H1,17HOUT-PUT ACRE-FEET,5X,5A4,I5)
      WRITE(IOUT,229)
      DO 75 L=1,12
75  WRITE(IOUT,234) OTL(L),(DVAR(L,J,K),K=1,6)
234  FORMAT(6X,A4,7F10.1)
      DO 76 L=2,14
      L1=L+12
76  WRITE(IOUT,234) OTL(L1),(SIM(L,K),K=1,6)
      WRITE(IOUT,234) OTL(27),(DVAR(13,J,K),K=1,6)
      WRITE(IOUT,234) OTL(28),(SIM(15,K),K=1,6)
      WRITE(IOUT,231)
      DO 77 L=1,12
77  WRITE(IOUT,234) OTL(L),(DVAR(L,J,K),K=7,12),AVAR(L)
      DO 78 L=2,14
      L1=L+12
78  WRITE(IOUT,234) OTL(L1),(SIM(L,K),K=7,12),ASIM(L)
      WRITE(IOUT,234) OTL(27),(DVAR(13,J,K),K=7,12),AVAR(13)
      WRITE(IOUT,234) OTL(28),(SIM(15,K),K=7,12),ASIM(15)
      WRITE(IOUT,1235) ASRD1,ASRD2
C    CONVERT QUANTITIES BACK TO INCHES
      DO 10 L=2,13
      DO 10 K=1,12
10  DVAR(L,J,K)=DVAR(L,J,K)*CAF
C    RESULTS OF RESERVOIR OPERATION
85  TSRD1=TSRD1+SRD1
      TSRD2=TSRD2+SRD2
86  CONTINUE
      FYR=NYR
      DF=12.*FYR
      TSRD1=TSRD1/DF
      XBR2=TVAR/DF
      DF=DF-2.
      TSRD2=TSRD2/(XBR2+XBR2+DF)
      OBJ=TSRD1
      IF(INPH,EQ.1) OBJ=TSRD2
      IF(IDOP,EQ.1) GO TO 87
      WRITE(IOUT,236) OBJ
236  FORMAT(/8H OBJ =,F10.6)
87  RETURN
      END

```

```

C SUBROUTINE TO SIMULATE MONTHLY HYDROLOGY
SUBROUTINE SIMH(J)
COMMON/BLK1/ ASIM(15),AVAR(14),CCR(14,12),CONV(14),
1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
3PRO(18), SBNM(5),SIM(15,12),VAR(12),
4WCR(12),WPH(12)
COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,GB0,
1IDCR, IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR, NVR,NYR,
2OBJ,RC0,SK,SNO,SNOW,SN01,SNW1,SRD1,SRD2, TACR,TAPH,TMP1,PR16
3,INPH
REAL MS1,MS
DO 68 K=1,12
SIM(1,K)=0.0

C SNOW STORAGE AND SNOW MELT FOR SIMULATED AREA
IF(DVAR(1,J,K).GT.PR(1).AND.DVAR(1,J,K).GT.PR(2)) GO TO 51
IF(DVAR(1,J,K).LE.PR(1).AND.DVAR(1,J,K).GT.PR(2)) GO TO 50
SIM(2,K)=SNO+DVAR(2,J,K)
SIM(3,K)=0.
RPMT=0.
J .52
50 SIM(2,K)=SNO+DVAR(2,J,K)
SIM(3,K)=SIM(2,K)*(1.-EXP(-PR(8)*(DVAR(1,J,K)-PR(2))))
IF(SIM(3,K).GT.SIM(2,K)) SIM(3,K)=SIM(2,K)
SIM(2,K)=SIM(2,K)-SIM(3,K)
RPMT=SIM(3,K)
J .52
51 SIM(3,K)=SNO*(1.-EXP(-PR(8)*(DVAR(1,J,K)-PR(2))))
IF(SIM(3,K).GT.SNO) SIM(3,K)=SNO
SIM(2,K)=SNO-SIM(3,K)
RPMT=DVAR(2,J,K)+SIM(3,K)
52 SNO=SIM(2,K)

C SNOW STORAGE AND SNOW MELT FOR UNGAGED AREA
TUNG=DVAR(1,J,K)-TMP1
IF(TUNG.GT.PR(1).AND.TUNG.GT.PR(2)) GO TO 41
IF(TUNG.LE.PR(1).AND.TUNG.GT.PR(2)) GO TO 40
SNW1=SN01+DVAR(2,J,K)
RPMT1=0.
J .42
40 SNW1=SN01+DVAR(2,J,K)
SNMT1=SNW1*(1.-EXP(-PR(8)*(TUNG-PR(2))))
IF(SNMT1.GT.SNW1) SNMT1=SNW1
SNW1=SNW1-SNMT1
RPMT1=SNMT1
J .42
41 SNMT1=SN01*(1.-EXP(-PR(8)*(TUNG-PR(2))))
IF(SNMT1.GT.SN01) SNMT1=SN01
SNW1=SN01-SNMT1
RPMT1=DVAR(2,J,K)+SNMT1
42 SN01=SNW1

C PHREATOPHYTE EVAPOTRANSPIRATION
BCF=DVAR(1,J,K)+DLH(K)
BCK=.0173+DVAR(1,J,K)*.314
IF(BCK.LT.0) BCK=.3
SIM(4,K)=PR(9)*WPH(K)+BCK*BCF
C CROP POTENTIAL EVAPOTRANSPIRATION AND IRRIGATION REQUIREMENT
IF(IDCR.EQ.0) GO TO 54
ETP=PR(9)+WCR(K)+BCK*BCF
DTIR=DVAR(5,J,K)+DVAR(7,J,K)+DVAR(9,J,K)-DVAR(11,J,K)
DAG=DTIR+PR(10)+RPMT
J .55
54 ETP=0.
DTIR=0.
DAG=0.
55 DTMI=DVAR(6,J,K)+DVAR(8,J,K)+DVAR(10,J,K)-DVAR(12,J,K)

C RETURN FLOW
IF(IDCR.EQ.0) GO TO 56
SIM(9,K)=(1.-PR(10))*DTIR+(1.-PR(11))*DTMI
ASCL=TACR
J .57
56 SIM(9,K)=(1.-PR(11))*DTMI
C UNGAGED SURFACE INFLOW
57 CCC=12.*AUNG/(ACOR*ASCL)

SIM(8,K)=PR(5)+CCC*CORS(J,K)+PR(12)+RPMT1+AUNG/ASCL+
1PR(13)*(AGAG+AUNG)/ASCL
C EVAPOTRANSPIRATION, SOIL MOISTURE AND PERCOLATION
IF(IDCR.EQ.0) GO TO 63
NITR=1
58 SIM(5,K)=ETP+MS1/PR(4)
IF(SIM(5,K).GT.ETP) SIM(5,K)=ETP
MS=PR16+DAG-SIM(5,K)
IF(MS.GT.PR(3)) GO TO 59
SIM(7,K)=0.
J .60
59 SIM(7,K)=MS-PR(3)
MS=PR(3)
60 DMS=ABS(MS-MS1)
IF(DMS.GT.ADMS.AND.NITR.LT.NITX) GO TO 61
J .62
61 NITR=NITR+1
MS1=(PR(16)+MS)/2.
J .60
62 SIM(6,K)=MS
PR16=SIM(6,K)
J .64
63 SIM(7,K)=0.
SIM(6,K)=0.
SIM(5,K)=0.

C GROUNDWATER RECHARGE AND OUTFLOW
64 DIN=PR(15)+RPMT1*(AGAG+AUNG)/ASCL
SK=PR(6)
DIC=RC0
CALL ROUT
RC0=DOUT
DIN=DVAR(4,J,K)+DOUT+SIM(7,K)-DVAR(9,J,K)-DVAR(10,J,K)
SK=PR(7)
DIC=GB0
CALL ROUT
GB0=DOUT
SIM(10,K)=PR(14)+DOUT
SIM(13,K)=DOUT-SIM(10,K)
SIM(4,K)=SIM(4,K)+TAPH/ASCL
SIM(14,K)=DVAR(3,J,K)-DVAR(7,J,K)-DVAR(8,J,K)-SIM(4,K)
1+SIM(9,K)+SIM(10,K)+SIM(8,K)+RPMT+TAPH/ASCL
SIM(12,K)=SIM(13,K)+SIM(14,K)
SIM(15,K)=SIM(14,K)-DVAR(13,J,K)
C CHECK AGAINST MINIMUM FLOW
IF(SIM(14,K).GE.DVAR(14,J,K)) GO TO 1064
SIM(11,K)=DVAR(14,J,K)-SIM(14,K)
J .65
1064 SIM(11,K)=0.
C CALCULATE ANNUAL SUMS
65 DO 66 L=1,NVR
AVAR(L)=AVAR(L)+DVAR(L,J,K)
C CALCULATE ANNUAL SUMS
DO 67 L=1,15
67 ASIM(L)=ASIM(L)+SIM(L,K)
SRD1=SRD1+ABS(SIM(15,K))/DVAR(13,J,K)
SRD2=SRD2+SIM(15,K)**2
68 CONTINUE
RETURN
END
C SUBROUTINE FOR LINEAR RESERVOIR ROUTING
SUBROUTINE ROUT
COMMON/BLK1/ ASIM(15),AVAR(14),CCR(14,12),CONV(14),
1CORS(4,12),CPH(5,12),CWT(2,5),DLH(12),DVAR(14,4,12)/BLK2/FMT1(4),
2FMT2(4),FMT3(4),FMT4(4),FMT5(4),IFMT(14),NST(14),OTL(28),PR(18),
3PRO(18), SBNM(5),SIM(15,12),VAR(12),
4WCR(12),WPH(12)
COMMON/BLK3/ACOR,ADMS,AGAG,ASCL,AUNG,BCF,BCK,CAF,DIC,DIN,DOUT,GB0,
1IDCR, IDOP,INN,IOUT,LYRO,MS1,NCR,NITX,NPH,NPR, NVR,NYR,
2OBJ,RC0,SK,SNO,SNOW,SN01,SNW1,SRD1,SRD2, TACR,TAPH,TMP1,PR16
3,INPH
REAL MS1
DOUT=DIN*(DIC-DIN)*EXP(-1./SK)
RETURN
END

```

# SAMPLE INPUT

## I. BASIC DATA

CARD 1  
PROV0 14 18 4 6 6 10

## II. TOTAL BASIN DATA

CARD 1  
TEMP+PPTGRIVQSMI+IRI+MII+QIR+QMI+IRP+MIP=IRX=MIX SNS=SMTETPH =ET MS =DPQUNG

CARD 2  
-QRF QBFQDEF QTD QGO QSOQGAGDIFF

CARD 3  
.077 .067 .065 .067 .067 .083 .089 .100 .101 .102 .096 .084 14 5 1

CARD 4

A1 ALPA 1 90 79 65 63 74 86 99 112 119 110 105 99

A2 PAST 2 80 74 58 55 66 81 86 102 99 93 91 87

A3 AQHA 3 84 77 62 55 66 81 94 109 115 110 105 95

A4 SMGR 4 22 29 29 29 29 28 74 118 127 73 40 19

A5 CORN 5 99 29 29 29 29 28 22 60 73 93 106 109

A6 SUBT 6 102 29 29 29 29 28 22 58 95 106 120 111

A7 POT 7 22 29 29 29 29 28 22 30 42 88 131 134

A8 ORCH 8 90 78 65 64 74 86 98 108 113 111 106 99

A9 PEAS 9

A10 TOMA10 40 29 29 29 29 28 45 50 75 101 97 83

A11 SHYR11 40 29 29 29 29 28 37 62 77 82 78 61

A12 IDLE12 35 30 25 25 25 30 33 38 39 39 39 39

A13 BEAN13 25 29 29 29 29 28 22 67 111 89 75 20

A14 BLAN14

CARD 5

C1 MWC 1 185 185 185 185 185 185 185 185 185 185 185 185

C2 MWGN 2 125 102 75 65 80 113 136 141 142 142 141 136

C3 MWGT 3 81 76 69 56 53 53 55 61 68 77 82 83

C4 LWGT 4 50 47 42 35 33 33 34 38 42 48 51 51

C5 OPWT 5 137 128 112 101 130 149 156 155 151 144 141 138

## III. IDOP

CARD 1

1

## IV. SUBBASIN DATA

CARD 1

FRANCIS 21376 109056 1 20 104320 5.2

CARD 2

1589 924 490 326 0 0 0 0

CARD 3

0 1 936 19 1 957 3329

CARD 4

1 3 5 0 0 0 8 0 0 0 2 0 1 0

CARD 5

.003604686 .003604686 .003604686 .003604686 .003604686 .003604686 .003604686 .003604686

CARD 6

.9393

CARD 7

.5841 .4963 .2111

## V. OBSERVED DATA

CARD 1

1964 0

CARD 2

OKL 64 3.7 3.4 3.0 2.6 2.0 2.3 4.6 44.1 56.5 19.2 7.3 4.7

OKL 65 3.6 3.4 3.6 3.2 3.0 2.8 8.7 40.3 78.9 38.0 13.0 9.2  
AAKL 66 6.6 5.2 4.6 4.1 3.3 4.7 14.9 48.2 24.9 8.4 5.0 4.1  
OKL 67 5.1 4.2 3.7 3.5 2.9 3.9 5.7 35.4 75.9 34.5 9.8 3.5

CARD 3

1 2 3 3 3 3 3 3 3 3 3 3 3

CARD 4

(14X,12F5,1) (14X,12F5,2) (8X,-3P12F6,1) (8X,12F6,1) (8X,12F6,1)

CARD 5

VAR(1) STATION 1

HEBER 1964 527 374 233 168 175 244 417 510 574 681 651 558 426

HEBER 1965 503 309 264 258 263 316 447 489 568 660 621 511 434

HEBER 1966 492 391 296 194 198 350 431 541 597 683 655 586 451

HEBER 1967 459 385 206 229 243 379 409 493 565 681 668 585

VAR(2) STATION 1

KAMAS PPT 1964 124 170 55 193 102 182 268 141 380 74 55 46

KAMAS PPT 1965 25 271 522 175 82 76 224 162 151 472 139 210

KAMAS PPT 1966 22 348 195 130 922 108 95 117 27 76 114 134

KAMAS PPT 1967 190 203 292 242 84 176 245 418 267 64 74 140

VAR(2) STATION 2

HEBER 1964 77 174 43 207 25 126 168 202 355 57 44 29 1507

HEBER 1965 27 224 540 179 44 67 143 81 117 91 113 141 1767

HEBER 1966 14 331 210 50 190 46 65 154 66 20 72 169 1228

HEBER 1967 120 188 322 338 46 175 138 238 202 58 78 53

VAR(2) STATION 3

SL 1964 232 374 141 673 153 736 655 416 447 99 101 60

SL 1965 45 789 1295 598 285 250 537 239 246 265 429 494

SL 1966 00 881 599 261 330 301 252 199 75 214 103 222

SL 1967 309 414 282 566 340 504 658 547 332 71 104 134

THE REMAINING VAR(L) DATA IS INPUT UNTIL, IN THIS EXAMPLE, VAR(13)

STATION 1 DATA IS INPUT

VAR(13) STATION 1

19641550 3.6 5.1 4.9 4.9 4.6 5.1 9.6 79.9 88.1 22.8 6.9 3.9

19651550 3.4 4.7 6.3 6.3 5.1 5.5 19.5 81.2 93.8 52.7 16.1 7.4

19661550 6.2 4.7 4.2 3.8 3.6 6.6 25.3 76.3 23.0 5.2 2.5 3.1

19671550 5.2 5.9 7.8 6.9 6.0 9.4 14.2 69.4 86.3 37.9 10.1 5.8

## VI. PARAMETER INPUT

CARD 1

2

CARD 2

4000 3000 600 400 34 20 40 12 100 30 80 04 12 40 02 400

CARD 3

4

4 4 1 1 5 4 4 4 4 4 1 5 5 4 4

CARD 4

1 3600 4000

2 2800 3200

3 28 38

4 10 50

5 20 100

6 10 14

7 80 120

8 20 50

9 00 10

10 10 20

11 20 60

12 01 05

# SAMPLE OUTPUT

PROVO

NYR = 4

FRACTION DAY-LIGHT HOURS

.077 .067 .065 .067 .067 .063 .089 .100 .101 .102 .096 .084

CROP COEFFICIENTS

.06 .79 .05 .63 .74 .06 .09 1.12 1.19 1.10 1.05 .09  
 .06 .74 .05 .63 .74 .06 .09 1.02 1.09 .93 .91 .07  
 .04 .77 .02 .55 .06 .81 .04 1.09 1.15 1.10 1.05 .05  
 .22 .29 .29 .29 .29 .29 .22 1.10 1.27 .73 .40 .19  
 .09 .29 .29 .29 .29 .29 .22 .60 .73 .93 1.06 1.09  
 1.02 .29 .29 .29 .29 .29 .22 .50 .05 1.06 1.20 1.11  
 .22 .29 .29 .29 .29 .29 .22 .30 .42 .06 1.31 1.34  
 .06 .78 .05 .64 .74 .06 .09 1.00 1.13 1.11 1.06 .09  
 .06 .06 .06 .06 .06 .06 .06 .06 .06 .06 .06 .06  
 .40 .29 .29 .29 .29 .29 .07 .62 .77 1.01 .07 .03  
 .40 .29 .29 .29 .29 .29 .07 .62 .77 .02 .78 .01  
 .35 .36 .25 .25 .25 .30 .33 .38 .39 .39 .30 .39  
 .25 .29 .29 .29 .29 .29 .22 .07 1.11 .09 .75 .20  
 .06 .06 .06 .06 .06 .06 .06 .06 .06 .06 .06 .06

PHREATOPHYTE COEFFICIENTS

1.05 1.05 1.05 1.05 1.05 1.05 1.05 1.05 1.05 1.05 1.05 1.05  
 1.25 1.02 .75 .05 .05 .05 1.13 1.36 1.41 1.42 1.42 1.41 1.36  
 .01 .75 .60 .56 .53 .53 .55 .61 .66 .77 .82 .83  
 .06 .47 .42 .35 .33 .33 .34 .38 .42 .48 .51 .51  
 1.37 1.20 1.12 1.01 1.30 1.49 1.06 1.06 1.51 1.44 1.41 1.30

FRANCIS

AGAG = 21376, AUNG = 109056, ACOR = 104320, IDCR = 1

CROP AREAS

1509. 924. 490. 320. 0. 0. 0. 0.  
 0. 0. 0. 0. 0. 0. 3329. 0.

WEIGHTED CROP COEFFICIENT

.79 .72 .59 .56 .66 .70 .92 1.09 1.13 1.01 .94 .07

PHREATOPHYTE AREAS

0. 1. 936. 19. 1. 957.

WEIGHTED PHREATOPHYTE COEFFICIENT

.80 .75 .66 .55 .52 .52 .54 .60 .67 .76 .81 .82

NUMBER OF STATIONS FOR EACH VARIABLE

1 3 5 0 0 0 0 0 0 0 2 0 1 0

CONVERSION FACTORS

.000000 .000000 .003604 .003604 .003604 .003604 .003604 .003604  
 .003604 .003604 .003604 .003604 .003604 .003604

STATION WEIGHTS FOR TEMPERATURE

.939

STATION WEIGHTS FOR PRECIPITATION

.504 .496 .211

CORR. STREAMFLOW

3.7 3.4 3.0 2.6 2.0 2.3 4.6 44.1 56.5 19.2 7.3 4.7  
 3.0 3.4 3.0 3.2 3.0 2.0 8.7 40.3 70.9 30.0 13.0 9.2  
 6.0 5.2 4.6 4.1 3.3 4.7 14.9 48.2 24.9 8.4 5.0 4.1  
 5.1 4.2 3.7 3.5 2.9 3.9 5.7 35.4 70.9 34.5 9.8 3.5

FRANCIS

PARAMETER RANGE, NO. OF INCREMENTS AND INITIAL VECTOR

JJ	PRL	PRH	NLV	PRO
1	36.00	40.00	4	40.00
2	28.00	32.00	4	30.00
3	6.00	6.00	1	6.00
4	4.00	4.00	1	4.00
5	.20	.30	5	.34
6	.10	.50	4	.20
7	.20	1.00	4	.40
8	.10	.14	4	.12
9	.00	1.20	4	1.00
10	.20	.60	4	.30
11	.00	.00	1	.00
12	.00	.10	5	.04
13	.10	.20	5	.12
14	.20	.00	4	.40
15	.01	.05	4	.02
16	4.00	4.00	1	4.00
17	4.00	4.00	1	4.00
18	3.00	3.00	1	3.00

PHASE 1

PAR	LVL	PAR. V.	OBJ	GRAD
1	1	36.00	.01424	
1	2	37.00	.01300	-.00027750
1	3	38.00	.01402	.00000171
1	4	39.00	.01409	.00000349
1	5	40.00	.01400	-.00000011
2	1	28.00	.01302	
2	2	29.00	.01306	.00033720
2	3	30.00	.01400	.00072200
2	4	31.00	.01514	.00105002
2	5	32.00	.01640	.00131005
5	1	.20	.00922	
5	2	.30	.00907	.01784091
5	3	.32	.01119	.00103401
5	4	.34	.01400	.14421072
5	5	.36	.01023	.20740345
5	6	.38	.02364	.27000003
6	1	.10	.01400	
6	2	.20	.01400	.00000404
6	3	.30	.01400	.00001700
6	4	.40	.01400	.00002270
6	5	.50	.01400	.00000005
7	1	.20	.01400	
7	2	.40	.01400	-.00000230
7	3	.60	.01400	.00000324
7	4	.80	.01400	.00001074
7	5	1.00	.01407	-.00000200
8	1	.10	.01402	
8	2	.11	.01430	-.03101930
8	3	.12	.01400	-.02200771
8	4	.13	.01304	-.01390402
8	5	.14	.01306	-.00740026
9	1	.00	.01475	
9	2	.00	.01441	-.00345032
9	3	1.00	.01400	-.00330105
9	4	1.10	.01376	-.00322593
9	5	1.20	.01347	-.00203002
10	1	.20	.01542	
10	2	.30	.01400	-.01330750
10	3	.40	.01294	-.01142414
10	4	.50	.01191	-.01002503
10	5	.60	.01090	-.00922393
12	1	.00	.00018	
12	2	.02	.00096	.03000747
12	3	.04	.01400	.20616793
12	4	.06	.02155	.37352734
12	5	.08	.03237	.54000054
12	3	.10	.04653	.70024033

13	1	.10	.01316	
13	2	.12	.01408	.04590582
13	3	.14	.01524	.05796077
13	4	.16	.01664	.07001441
13	5	.18	.01828	.08207131
13	6	.20	.02016	.09412580
14	1	.20	.01171	
14	2	.30	.01280	.01092022
14	3	.40	.01408	.01277346
14	4	.50	.01554	.01462640
14	5	.60	.01719	.01647960
15	1	.01	.01278	
15	2	.02	.01408	.12960934
15	3	.03	.01556	.14771279
15	4	.04	.01721	.16572588
15	5	.05	.01905	.18373879

THE OPTIMAL FACTORS ARE AS FOLLOWS

40.00	30.00	6.00	4.00	.34	.20	.40	.12
1.00	.30	.60	.00	.12	.40	.02	4.00
4.00	3.00						

FRANCIS

1964

VAR	OCT	NOV	DEC	JAN	FEB	MAR
TEMP	49.501	35.129	21.885	15.780	18.437	22.918
+PPT	1.596	2.646	.832	3.575	1.842	3.242
QRIV	6.848	10.453	9.372	8.651	7.569	11.534
QGW1	.000	.000	.000	.000	.000	.000
+IR1	.000	.000	.000	.000	.000	.000
+M11	.000	.000	.000	.000	.000	.000
+Q1R	.000	.000	.000	.000	.000	.000
+IRP	.000	.000	.000	.000	.000	.000
+MIP	.000	.000	.000	.000	.000	.000
-IRX	.000	.000	.000	.000	.000	.000
-MIX	.000	.000	.000	.000	.000	.000
SNS	.000	1.429	2.262	5.837	6.888	10.122
+SMT	.000	1.216	.000	.000	.000	.000
ETPH	.478	.153	.084	.058	.058	.086
-ET	1.536	.511	.292	.178	.423	.423
MS	3.559	4.864	4.412	4.233	4.815	3.591
-DP	.000	.000	.000	.000	.000	.000
QUNG	9.442	9.857	8.545	8.832	7.264	7.648
-QRF	.000	.000	.000	.000	.000	.000
QBF	.594	.851	.804	.880	.880	.880
QDEF	.000	.000	.000	.000	.000	.000
QTO	17.758	19.837	17.844	16.834	14.783	19.096
QGO	.892	.877	.886	.801	.880	.880
QSO	18.866	19.759	17.837	16.833	14.783	19.096
QGAG	12.976	18.363	17.662	16.581	18.363	18.363
DIFF	3.889	1.375	.174	-1.829	-1.797	.713

VAR	APR	MAY	JUN	JUL	AUG	SEPT	ANN
TEMP	39.168	47.984	53.915	63.966	61.148	52.412	48.814
+PPT	3.781	2.784	4.925	.924	.752	.539	26.582
QRIV	14.858	211.955	251.687	71.733	23.798	8.298	635.866
QGW1	.000	.000	.000	.000	.000	.000	.000
+IR1	.000	.000	.000	.000	.000	.000	.000
+M11	.000	.000	.000	.000	.000	.000	.000
+Q1R	.000	7.938	23.438	23.869	18.221	8.651	79.383
+IRP	.000	.000	.000	.000	.000	.000	.000
+MIP	.000	.000	.000	.000	.000	.000	.000
-IRX	.000	2.162	6.488	9.372	5.846	2.923	25.593
-MIX	.000	.000	.000	.000	.000	.000	.000
SNS	4.827	.539	.838	.881	.880	.880	31.729
+SMT	9.277	4.887	.589	.830	.881	.000	15.120
ETPH	.199	.438	.855	1.138	1.823	.618	4.968
-ET	1.168	2.896	3.829	5.257	4.137	2.276	22.587
MS	6.000	6.000	6.000	5.806	5.774	5.875	60.332
-DP	5.699	5.824	.687	.000	.000	.000	18.212
QUNG	18.595	61.204	77.091	29.301	14.854	10.723	252.961
-QRF	.000	4.837	11.859	9.588	7.822	4.289	37.596

QBF	3.730	5.328	4.842	.734	.279	.178	15.744
QDEF	.000	.000	.000	.000	.000	.000	.000
QTO	36.445	284.189	330.140	68.525	29.339	14.635	889.150
QGO	5.595	7.992	7.263	1.101	.419	.267	23.617
QSO	30.850	276.116	322.876	87.423	28.919	14.567	865.531
QGAG	34.604	288.814	317.572	82.186	24.872	14.858	862.961
DIFF	-3.754	-11.897	5.303	5.236	4.847	.309	2.572

ASRD1 = .08373 ASRD2 = .00482

FRANCIS

1967

VAR	OCT	NOV	DEC	JAN	FEB	MAR
TEMP	43.113	36.183	19.349	21.509	22.824	35.599
+PPT	2.357	2.992	3.898	4.285	1.436	2.968
QRIV	7.930	10.893	14.418	13.337	10.814	18.221
QGW1	.000	.000	.000	.000	.000	.000
+IR1	.000	.000	.000	.000	.000	.000
+M11	.000	.000	.000	.000	.000	.000
+Q1R	.000	.000	.000	.000	.000	.000
+IRP	.000	.000	.000	.000	.000	.000
+MIP	.000	.000	.000	.000	.000	.000
-IRX	.000	.000	.000	.000	.000	.000
-MIX	.000	.000	.000	.000	.000	.000
SNS	.000	1.428	5.327	9.613	11.849	7.155
+SMT	.000	1.564	.000	.000	.000	.000
ETPH	.331	.163	.074	.089	.069	.135
-ET	1.142	.546	.222	.243	.303	.697
MS	6.000	6.000	5.777	5.533	5.230	6.000
-DP	1.854	1.817	.000	.000	.000	.000
QUNG	11.235	10.882	9.442	9.185	8.417	9.698
-QRF	.000	.000	.000	.000	.000	.000
QBF	.855	.568	.847	.883	.880	2.192
QDEF	.000	.000	.000	.000	.000	.000
QTO	21.652	21.882	23.985	22.463	19.182	33.237
QGO	1.284	.852	.871	.885	.880	.880
QSO	28.368	21.830	23.834	22.458	19.182	29.947
QGAG	18.744	21.287	28.116	24.872	21.828	33.884
DIFF	1.624	-.237	-4.282	-2.414	-2.466	-3.936

VAR	APR	MAY	JUN	JUL	AUG	SEPT	ANN
TEMP	38.417	46.307	53.878	63.986	62.745	54.949	41.581
+PPT	3.584	4.777	3.262	.811	1.838	1.363	32.691
QRIV	29.918	191.848	224.932	118.854	29.918	14.779	682.366
QGW1	.000	.000	.000	.000	.000	.000	.000
+IR1	.000	.000	.000	.000	.000	.000	.000
+M11	.000	.000	.000	.000	.000	.000	.000
+Q1R	.000	10.453	29.953	31.888	18.383	14.418	188.218
+IRP	.000	.000	.000	.000	.000	.000	.000
+MIP	.000	.000	.000	.000	.000	.000	.000
-IRX	.000	2.523	6.488	13.337	6.488	4.325	33.163
-MIX	.000	.000	.000	.000	.000	.000	.000
SNS	3.882	.546	.834	.881	.880	.880	39.848
+SMT	6.777	3.333	.514	.833	.881	.880	19.879
ETPH	.188	.393	.629	1.138	1.888	.696	4.979
-ET	1.105	2.467	3.679	5.257	4.403	2.563	22.633
MS	6.000	6.000	6.000	6.000	6.000	6.000	70.540
-DP	5.672	8.823	5.936	.887	.205	1.827	38.811
QUNG	12.804	58.857	101.947	48.984	17.257	9.185	297.419
-QRF	.000	5.551	13.625	12.364	8.326	7.865	46.932
QBF	3.986	7.340	4.593	1.856	.464	1.181	22.211
QDEF	.000	.000	.000	.000	.000	.000	.000
QTO	53.649	258.493	328.490	158.967	37.491	19.859	986.455
QGO	5.979	11.811	6.889	1.584	.697	1.651	33.317
QSO	47.669	245.482	319.600	149.383	36.794	17.488	953.138
QGAG	51.186	258.165	311.884	136.617	36.487	28.987	984.888
DIFF	-3.516	-4.683	8.516	12.765	.386	-3.499	-1.742

ASRD1 = .08030 ASRD2 = .00522

OBJ = .889183

## APPENDIX B

### DATA PROGRAM

The data program and the river basin management model are designed to be operated in conjunction. The data program is used to prepare a data tape which is used as part of the input for the river basin management model.

The time sequence of the data program must be the same as the time sequence used in the river basin management model. All sample input and output are based on a water year but this program is not tied to any particular time sequence.

The data program inputs the observed data as outlined in the input data layout and illustrated in the sample input. The program sums the stations for each variable to form a single monthly quantity. The temperature and precipitation data are not summed but are averaged using input weighting factors. The resulting tape consists of one value for each of the subbasin and reservoir variables, VAR(C) and RVAR(C), respectively, for each month of the study.

The data for each variable, VAR(L), must be in the same units within each subbasin. This requires all stations of a particular variable to be input in the same units. This restriction does not affect input data for different subbasins. The reservoir variable, RVAR(L), data must be input in acre feet.

Water input as irrigation or municipal and industrial import will be designated to that use and will only enter the stream as return flow. Export of irrigation or municipal and industrial water is accomplished by divert-

ing the water in VAR(7) and VAR(8), respectively, and then exporting the water under VAR(11) and VAR(12).

The values output on the tape are arranged by month for each year. Within each month the data are arranged according to subbasin. The subbasin data consist of the VAR(L) data followed, when appropriate, by the RVAR(L) data.

The program outputs a listing of the data which appears on the tape. The listing output by the data program differs from what appears on the corresponding tape only in the additional output of headings for year and month. These headings are output to aid in locating specific input and, therefore, do not appear on the tape.

The sample input and output is for a three subbasin case with a reservoir located in the second subbasin. The sample input is supplemented with cards referring to the location of cards in the input data layout. These cards should not be mistaken for actual input.

The data listing is divided so the individual subbasin data can be distinguished. The sample output corresponds to the three subbasin case used as sample input. The variable, VAR(L), data output consists of two lines for each subbasin. The reservoir data, RVAR(L), for the second subbasin follows on a separate line after the variable data for that subbasin. The VAR(L) and RVAR(L) are listing across the page in the same order they appear in Table C-1.

# INPUT DATA LAYOUT

## I. Basic Indicators

	Col	Identifier	
Card 1	1-6	NMDTA	Data tape name
			Format (3A2)
Card 2	1-4	INN	Input device indicator
	5-8	IOT1	Output device indicator for print
	9-12	IOUT2	Output device indicator for tape
	13-16	NYR	Number of years of data
	17-20	NSB	Number of subbasins within the river basin
	21-24	NVR	Number of variables; corresponds to number of VAR(1) in Table C-1
	25-28	NRVR	Number of reservoir variables; corresponds to number of RVAR(L) in Table C-1
	29-32	LYRO	Beginning year of data
			Format (20I4)

## II. Input Formats and Format Indicators

Card 1	1-16	FMT1	A specific input format
	17-32	FMT2	A specific input format
	.	.	.
	.	.	.
	65-80	FMT5	A specific input format
			Format (5(4A4))
Card 2	4	IFMT(1,1)	Read format indicator for Subbasin 1 VAR(1)
	8	IFMT(1,2)	Read format indicator for Subbasin 1 VAR(2)
	.	.	.
	.	.	.
	.	.	.
		IFMT(1,NVR)	Read format indicator for Subbasin 1 VAR(NVR)
			Format (20I4)

This input is repeated for Subbasins 2, 3, ..., NSB. The options for IFMT(I, L) are to input a 1 to 5 correspondence to which format, FMT1 to FMT5 respectively, is desired from Card 1 above.

## III. Number of Stations

	Col	Identifier	
Card 1	1-4	NST(1,1)	Number of stations for Subbasin 1 VAR(1)
	5-8	NST(1,2)	Number of stations for Subbasin 1 VAR(2)
	.	.	.
	.	.	.
	.	.	.
		NST(1,NVR)	Number of stations for Subbasin 1 VAR(NVR)
		NRST(1,1)	Number of stations for Subbasin 1 RVAR(1)
		NRST(1,2)	Number of stations for Subbasin 1 RVAR(2)
	.	.	.
	.	.	.
	.	.	.
		NRST(1,NVR)	Number of stations for Subbasin 1 RVAR(NVR)
			Format (20I4)

This input is repeated for Subbasins 2, 3, ..., NSB.

## IV. Station Weight for Temperature and Precipitation

Card 1&2	1-5	CWT(1,1,1)	Weight factor to be applied to temperature Station 1 Subbasin 1
	6-10	CWT(1,1,2)	Weight factor to be applied to temperature Station 2 Subbasin 1
	.	.	.
	.	.	.
	.	.	.
		CWT[1,1,NST(1,1)]	Weight factor to be applied to temperature Station NST(1,1) Subbasin 1
			Format (16F5.2)

The next card of this group contains the precipitation weight factor for Subbasin 1.

1-5	CWT(1,2,1)	Weight factor to be applied to precipitation Station 1 Subbasin 1
6-10	CWT(1,2,2)	Weight factor to be applied to precipitation Station 2 Subbasin 1

.  
 .  
 .  
 CWT[1,2,NST Weight factor to be applied to precipitation  
 (1,2)]  
 Station NST(1,2) Sub-  
 basin 1  
 Format (16F5.2)

A similar set of cards is input for Subbasins 2, 3, ..., NSB.

#### V. Reservoir Indicator

Card	4	IRS(1)	Reservoir indicator for Subbasin 1
1			
	8	IRS(2)	Reservoir indicator for Subbasin 2
		IRS(NSB)	Reservoir indicator for Subbasin NSB.

Format (20I4)

Where:

- 0 - indicates no reservoir at the outlet of the subbasin
- 1 - indicates a reservoir is at the outlet of the subbasin

#### VI. Observed Data

Card The following ordering of cards, each containing twelve monthly values, is to be repeated for year 1, 2, 3, ..., NYR.

Subbasin 1

VAR(1)	Station 1, 2, ..., NST(1,1)
VAR(2)	Station 1, 2, ..., NST(1,2)
.	.
.	.
VAR(NVR)	Station 1, 2, ..., NST(1,NVR)

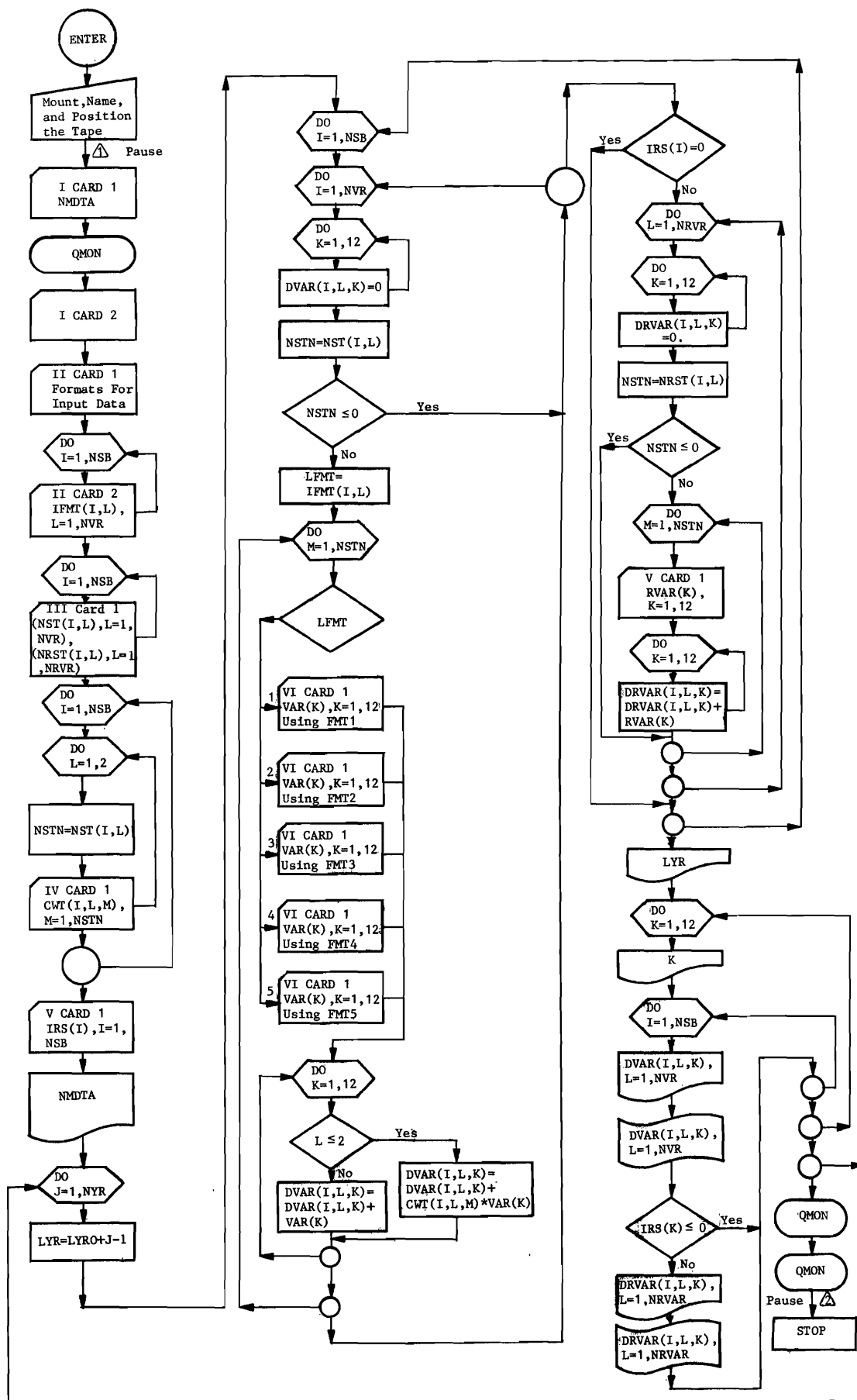
If IRS(1) = 0, skip RVAR(L) input

RVAR(1)	Station 1, 2, ..., NRST(1,1)
RVAR(2)	Station 1, 2, ..., NRST(1,2)
.	.
.	.
RVAR(NRVR)	Station 1, 2, ..., NRST(1,NRVR)

This arrangement of cards is repeated for Subbasins 2, 3, ..., NSB before going to data for the next year. (See sample input.)

The VAR(L) data is input with one year of monthly data per card according to the format specified in cards 1 and 2 of II. As an example, if IFMT (3,6) = 2 on card 2, VAR(6) data for Subbasin 3 is input according to FMT2 on card 1. When any NST(I,L) or NRST(I,L) is equal to zero, no cards are input for that VAR(L) or RVAR(L), respectively, of Subbasin I.





## DATA PROGRAM LISTING

```

C
C   PREPARE OBSERVED DATA IN PROPER FORMAT
C   DIMENSION CWT(8,2,5),DVAR(8,14,12),DRVAR(8,2,12),FMT1(4),FMT2(4),
1FMT3(4),FMT4(4),FMT5(4),IFMT(8,14),IRS(8),NST(8,14),NRST(8,2),
2VAR(12),RVAR(12)
C   DIMENSION NMDTA(3)
C
C   INPUT BASIC INDICATORS
C   TYPE 199
199 FORMAT(34H MOUNT NAME AND POSITION THE TAPE/)
OCT 25000
READ(6,99) (NMDTA(I),I=1,3)
99 FORMAT(3A2)
CALL QMON(21,NMDTA(1),8,13)
READ(6,100) INN,IOT1,IOT2,NYR,NSB,NVR,NVRV,LYR0
100 FORMAT(20I4)
C
C   READ FORMAT FOR INPUT DATA
C   READ(INN,101) (FMT1(L),L=1,4),(FMT2(L),L=1,4),(FMT3(L),L=1,4),
1(FMT4(L),L=1,4),(FMT5(L),L=1,4)
101 FORMAT(5(4A4))
C
C   INPUT FORMAT INDICATOR FOR INPUT DATA
C   DO 2 I=1,NSB
2 READ(INN,100) (IFMT(I,L),L=1,NVR)
C
C   INPUT NUMBER OF STATIONS FOR EACH VARIABLE AND RESERVOIR VARIABLE
C   DO 3 I=1,NSB
3 READ(INN,100) (NST(I,L),L=1,NVR),(NRST(I,L),L=1,NVRV)
C
C   INPUT STATION WEIGHT FOR TEMPERATURE AND PRECIPITATION
C   DO 4 I=1,NSB
C   DO 4 L=1,2
C   NSTN=NST(I,L)
4 READ(INN,102) (CWT(I,L,M),M=1,NSTN)
102 FORMAT(10F5,2)
C   INPUT RESERVOIR INDICATOR
C
C   READ(INN,100) (IRS(I),I=1,NSB)
C   WRITE(6,98) (NMDTA(L),L=1,3)
98 FORMAT(1X,3A2)
C
C   INPUT AND REARRANGE OBSERVED DATA
C   DO 19 J=1,NYR
C   LYR=LYR0+J-1
C   DO 17 I=1,NSB
C   DO 20 L=1,NVR
C   DO 5 K=1,12
5 DVAR(I,L,K)=0.
C   NSTN=NST(I,L)
C   IF(NSTN.LE.0) GO TO 20

```

```

C   LFMT=IFMT(I,L)
C   DO 13 M=1,NSTN
C   GO TO (6,7,8,9,10),LFMT
6 READ(INN,FMT1) (VAR(K),K=1,12)
C   J=.11
7 READ(INN,FMT2) (VAR(K),K=1,12)
C   J=.11
8 READ(INN,FMT3) (VAR(K),K=1,12)
C   J=.11
9 READ(INN,FMT4) (VAR(K),K=1,12)
C   J=.11
10 READ(INN,FMT5) (VAR(K),K=1,12)
11 DO 22 K=1,12
C   IF(L.LE.2) GO TO 12
C   DVAR(I,L,K)=DVAR(I,L,K)+VAR(K)
C   J=.22
12 DVAR(I,L,K)=DVAR(I,L,K)+CWT(I,L,M)*VAR(K)
22 CONTINUE
13 CONTINUE
20 CONTINUE
C   IF(IRS(I).EQ.0) GO TO 17
C   DO 21 L=1,NVRV
C   DO 14 K=1,12
14 DRVAR(I,L,K)=0.
C   NSTN=NRST(I,L)
C   IF(NSTN.LE.0) GO TO 16
C   DO 16 M=1,NSTN
C   READ(INN,103) (RVAR(K),K=1,12)
C   DO 15 K=1,12
15 DRVAR(I,L,K)=DRVAR(I,L,K)+RVAR(K)
16 CONTINUE
21 CONTINUE
17 CONTINUE
C
C   OUTPUT DATA FOR MANAGEMENT STUDY
C   WRITE(IOT1,250) LYR
250 FORMAT(//7H YEAR =,I4)
C   DO 18 K=1,12
C   WRITE(IOT1,251) K
251 FORMAT(/4H K =,I2)
C   DO 18 I=1,NSB
C   WRITE(IOT1,200) (DVAR(I,L,K),L=1,NVR)
C   WRITE(IOT2,200) (DVAR(I,L,K),L=1,NVR)
200 FORMAT(2F8,3,5F8,0/10F8,0)
C   IF(IRS(I).LE.0) GO TO 18
C   WRITE(IOT1,201) (DRVAR(I,L,K),L=1,NVRV)
C   WRITE(IOT2,201) (DRVAR(I,L,K),L=1,NVRV)
201 FORMAT(10F8,0)
18 CONTINUE
19 CONTINUE
C   CALL QMON(15)
C   CALL QMON(15)
C   OCT 25000
C   STOP
C   END

```

## SAMPLE INPUT

### I. BASIC INDICATORS

CARD 1

OBDTA2

CARD 2

6 13 6 26 3 13 21958

### II. INPUT FORMATS AND FORMAT INDICATORS

CARD 1

(14X,12F5,1) (14X,12F5,2) (8X,-3P12F5,1) (8X,12F5,1) (8X,12F5,1)

CARD 2

1 2 3 3 3 3 3 3 3 3 3 3 3  
1 2 3 3 3 3 3 3 3 3 3 3 3  
1 2 3 3 3 3 3 3 3 3 3 3 3

### III. NUMBER OF STATIONS

CARD 1

1 3 6 0 0 0 0 0 0 0 2 0 1 0 0  
1 3 3 0 0 0 0 12 0 0 0 0 0 1 1 1  
1 3 1 0 0 0 10 2 1 1 0 3 1 0 0

### IV. STATION WEIGHT FOR TEMPERATURE AND PRECIPITATION

CARD 1 AND 2

.9393

.5841,4963,2111

1.808

.5804,1889,3518

1.908

.6488,2814,3918

### V. RESERVOIR INDICATORS

CARD 1

0 1 0

### VI. OBSERVED DATA

CARD 1

VAR(1) STATION 1,SUBBASIN 1,YEAR 1  
1958 436 482 223 177 256 348 438 477 567 649 625 592 438  
VAR(2) STATION 1,SUBBASIN 1,YEAR 1  
1958 285 169 296 318 111 148 74 176 30 45 0 115 1884  
VAR(2) STATION 2,SUBBASIN 1,YEAR 1  
KAMAS PPT 1958 282 126 182 283 138 194 98 214 48 30 88 118  
VAR(2) STATION 3,SUBBASIN 1,YEAR 1  
SL 1958 582 247 751 894 278 771 337 345 87 88 17 318

THE REMAINING VAR(L) DATA IS INPUT TO SUBBASIN 1 FOR YEAR 1 UNTIL,  
IN THIS EXAMPLE, VAR(13) STATION 1 DATA IS INPUT

VAR(13) STATION 1,SUBBASIN 1,YEAR 1  
1958 1958 5.8 4.4 3.5 3.4 3.7 5.4 18.2 46.6 62.2 18.9 7.5 3.9

THE INPUT OF VAR(L) AND RVAR(L) FOR THE SECOND AND THIRD SUBBASINS  
FOLLOW THIS INPUT

SIMILAR DATA IS THEN INPUT FOR YEARS 2,3,...,28

## SAMPLE OUTPUT

OBDTA2

YEAR =1958

K = 1

40,953	3,656	888.	0.	0.	0.	0.
0.	0.	0.	0.	0.	5888.	0.
43,599	3,232	3888.	0.	0.	0.	0.
0.	0.	0.	0.	0.	13688.	0.
13688.	0.	0.	0.	0.	0.	0.
47,588	4,150	-188.	0.	0.	0.	0.
1888.	0.	588.	0.	2888.	13988.	0.

K = 2

37,759	2,133	1188.	0.	0.	0.	0.
0.	0.	0.	0.	0.	4488.	0.
48,199	2,372	4688.	0.	0.	0.	0.
0.	0.	0.	0.	0.	14688.	0.
14688.	0.	0.	0.	0.	0.	0.
42,899	1,966	888.	0.	0.	0.	0.
0.	0.	488.	0.	488.	16888.	0.

K = 3

28,948	4,217	1188.	0.	0.	0.	0.
0.	0.	0.	0.	0.	3588.	0.
22,388	4,388	2788.	0.	0.	0.	0.
0.	0.	0.	0.	0.	13388.	0.
13388.	0.	0.	0.	0.	0.	0.
28,399	4,389	1888.	0.	0.	0.	0.
0.	0.	488.	0.	388.	16688.	0.

K = 4

16,625	5,131	1188.	0.	0.	0.	0.
0.	0.	0.	0.	0.	3488.	0.
17,699	4,678	6888.	0.	0.	0.	0.
0.	0.	0.	0.	0.	16788.	0.
16788.	0.	0.	0.	0.	0.	0.
24,199	4,816	1388.	0.	0.	0.	0.
0.	0.	488.	0.	388.	18888.	0.

K = 5

24,848	1,928	1588.	0.	0.	0.	0.
0.	0.	0.	0.	0.	3788.	0.
25,599	1,434	6788.	0.	0.	0.	0.
0.	0.	0.	0.	0.	14688.	0.
14688.	0.	0.	0.	0.	0.	0.
34,299	1,576	-2388.	0.	0.	0.	0.
0.	0.	488.	0.	388.	16388.	0.

K = 6

32,687	3,454	2188.	0.	0.	0.	0.
0.	0.	0.	0.	0.	5488.	0.
34,799	2,733	1288.	0.	0.	0.	0.
0.	0.	0.	0.	0.	17888.	0.
17888.	0.	0.	0.	0.	0.	0.
48,399	2,841	-1588.	0.	0.	0.	0.
0.	0.	488.	0.	488.	19888.	0.

K = 7

41,141	1,598	6888.	0.	0.	0.	0.
0.	0.	0.	0.	0.	18288.	0.
43,799	1,383	5988.	0.	0.	0.	2288.
0.	0.	0.	0.	0.	28688.	0.
28688.	0.	0.	0.	0.	0.	0.
49,899	1,428	-788.	0.	0.	0.	7288.
3588.	1888.	588.	0.	3988.	14788.	0.

## APPENDIX C

### RIVER BASIN MANAGEMENT MODEL

The river basin management model was designed to be as general as possible in adaption to various time sequences and units of input. The program was designed for use on the EAI 590 hybrid computer. The program presented is completely digital and contains logic statement peculiar to this computer. The program, as presented, is operated for each month of the water year. Conversion to a different time sequence requires the input data and output headings which rely on monthly ordering to be rearranged.

The input to the program is outlined in the input data layout. The major portion of the input comes from the tape created by the data program. A dummy scaling area, ASCL, must be input for each subbasin which does not contain agricultural area. It is suggested that the

magnitude of ASCL be the same as used in the Parameter Optimization Model. There must be at least one phreato-phyte area within each subbasin.

The sample input and output is for the three subbasin case used to illustrate the use of the data program. A reservoir is located in the second subbasin in the sample case. The sample input is supplemented with cards referring to the location of cards in the input data layout. These cards should not be mistaken for actual input.

The output from the program is by month. The subbasin output is followed by the reservoir output within each month. The reservoir output is labeled according to which subbasin contains the reservoir.

# INPUT DATA LAYOUT

I. Basic Data				18-20	NITX	Maximum number of iterations in loop involving calculation of soil moisture
	<u>Col</u>	<u>Identifier</u>				
Card 1	1-6	NMDTA	Name of data tape produced by data program	21-25	AJSO	Tolerance in meeting downstream demands. If the total adjustment to the release from a reservoir is less than this amount, no adjustment to the release is made. AJSO is in acre feet
			Format (3A2)			
Card 2	1-16	BSNM	The river basin name			
	17-19	NSB	Number of subbasins within the river basin			
	20-22	NVR	Number of variables; corresponds to number of VAR(L) in Table C-1	26-30	ADMS	Tolerance desired in the calculation of soil moisture. ADMS is in inches of water
	23-25	NPR	Number of parameters; corresponds to number of PR(L) in Table C-2	31-35	CAJS	A multiplication factor which can be used to alter the adjustment to the reservoir release (See below)
	26-28	NSM	Number of simulated quantities; corresponds to number of SIM(L) in Table C-3	36-40	ITOP	Subbasin number of the most upstream subbasin containing a reservoir
	29-31	NRVR	Number of reservoir variables; corresponds to number of RVAR(L) in Table C-1	41-45	DAJS	An additive factor which can be used to alter the adjustment to the reservoir release (see below)
	32-34	NRPR	Number of reservoir parameters; corresponds to number of RPR(L) in Table C-2			DAJS in acre feet
	35-37	NRSM	Number of simulated reservoir quantities; corresponds to number of RSIM(L) in Table C-3			Format (I5, 5I3, 3F5.2, I5, F5.0)
	38-40	NIND	Number of basic indicators; corresponds to number of IND(L) in Table C-4	Where:		
	41-43	NARA	Number of areas; corresponds to number of AREA(L) in Table C-4	TAJS = CAJS*(SAJS + QAJS) + DAJS		
	44-46	NSIC	Number of initial conditions; corresponds to number of SYIC(L) in Table C-4	TAJS = Total adjustment to previous reservoir release		
			Format (4A4, 10I3)	With CAJS = 1.0 and DAJS = 0 the adjustment will consist of the exact downstream shortage to desired amounts. The release of additional water from an upstream reservoir effects many components of the downstream hydrology which can result in less than TAJS acre feet of water reaching the downstream check point. If the new calculated TAJS is greater than AJSO the program will iterate until the total release is sufficient to meet downstream requirements. The proper use of CAJS and DAJS can reduce the number of iterations.		
Card 3	1-5	LYRO	Beginning year of study	Card 4	1-4	OTL(1) SIM(1) Output title
	6-8	NYR	Number of years to be studied by the program		5-8	OTL(2) SIM(2) Output title
	9-11	IN1	Input device code for cards		.	.
	12-14	IN2	Input device code for tape		.	.
	15-17	IOUT	Output device code		.	.
					OTL(L)	SIM(L) Output title
						Format (20A4)

Table C-1. Definition of variable.

L	Variables VAR(L)	Reservoir Variables RVAR(L)
1	Mean monthly temperature	Minimum reservoir storage
2	Total monthly precipitation	Diversion from reservoir
3	Gaged surface inflow	
4	Gaged or estimated groundwater inflow	
5	Irrigation import	
6	M&I import	
7	Irrigation surface flow diversions	
8	M&I surface flow diversions	
9	Irrigation pumpage	
10	M&I pumpage	
11	Irrigation export	
12	M&I export	
13	Gaged surface outflow	

Table C-2. Definition of parameters.

L	Parameters PR(L)	Equation	Reservoir Parameters RPR(L)
1	Snowfall temperature	Chapter 3 precipitation section	Minimum reservoir storage
2	Snowmelt temperature	3.3 $T_m$	Lower break point for surface area equation
3	Soil moisture holding capacity	3.27 $M_{cs}$	High break point for surface area equation
4	Critical soil moisture	3.27 $M_{es}$	Maximum reservoir storage
5	Ungaged stream correlation coefficient	3.7 $K_1$	Low range coefficient, $C_1$
6	Subsurface storage coefficient	3.33 $K_{ss}$	Low range exponent, $C_2$
7	Groundwater storage coefficient	3.35 $K_g$	Intermediate range coefficient, $C_1$
8	Snowmelt coefficient	3.4 $K_s$	Intermediate range exponent, $C_1$
9	Consumptive use coefficient	3.25 $K_u$	High range coefficient, $C_1$
10	Irrigation efficiency	3.13 $Eff$	High range exponent, $C_2$
11	M&I efficiency	3.16 $Eff_{mi}$	
12	Coefficient of rain plus snowmelt for ungaged flow	3.7 $K_2$	
13	Threshold for surface runoff	3.7 $K_3$	
14	Base flow coefficient	3.36 $K_{bf}$	
15	Infiltration coefficient	3.33 $C_i$	

Table C-3. Definition of simulated quantities.

L	Simulated Quantities SIM(L)	Equation	Simulated Reservoir Quantities RSIM(L)
1	Snow storage	3.5 $W_s(t)$	Reservoir inflow
2	Ungaged surface inflow	3.7 $Q_{ug}$	Reservoir precipitation
3	Imported flow	VAR(5) + VAR(6)	Reservoir evaporation
4	Return flow	3.15, 16 $Q_{ri} + Q_{rmi}$	Reservoir storage diversion
5	Base flow	3.36 $Q_{bf}$	Reservoir spill flow
6	Pumped and artesian flow	VAR(9) + VAR(10)	Reservoir release
7	Deep percolation	3.29, 30 $DP_r$	Reservoir storage
8	Groundwater inflow	VAR(4) + $Q_{GRY}(I-1)$	
9	Flow to irrigation	4.4 or input data	
10	Flow to M&I	Input data	
11	Exported flow	VAR(11) + VAR(12)	
12	Flow shortage	$QDSIR(I)$ - SIM(18)	
13	Phreatophyte evapotranspiration	3.25 $ET_{pr}$	
14	Crop evapotranspiration	3.26, 27 $ET_r$	
15	Soil moisture	3.19 $M_s(t)$	
16	Total outflow	3.39 $Q_{to}$	
17	Groundwater outflow	3.37 $Q_{go}$	
18	Surface outflow	3.38 $Q_{so}$	

Table C-4. Definition of model indicators.

L	Indicators IND(L)	Areas Area(L)	Initial conditions SYIC(L)
1	Number of cards	Gaged watershed area	Initial snow storage
2	Number of phreatophytes	Ungaged watershed area	Initial soil moisture, PR(16) <sup>a</sup>
3	Irrigation management indicator	Scaling area	NOT USED
4	Upstream reservoir indicator	Correlation stream drainage area	Initial watershed recharge, PR(18) <sup>a</sup>
5	Downstream reservoir indicator		Initial groundwater and base outflow, PR(17) <sup>a</sup>
6			Initial reservoir storage

<sup>a</sup>See Table A-1.

Card 1-4 ROTL(1) RSIM(1) Output title  
5 5-8 ROTL(2) RSIM(2) Output title

.  
.  
.  
ROTL(L) RSIM(L) Output title  
Format (20A4)

Card 1-4 OTLV(1) VAR(1) Output title  
6 (temperature)  
5-8 OTLV(2) VAR(2) Output title  
(precipitation)  
9-12 OTLV(3) VAR(3) Output title  
(gaged inflow)  
13-16 OTLV(4) VAR(13) Output title  
(gaged outflow)

Format (20A4)

Card 1-5 DLH(1) Fraction daylight hour  
7 for month 1  
6-10 DLH(2) Fraction daylight hour  
for month 2  
.  
.  
.  
56-60 DLH(12) Fraction daylight hour  
for month 12  
61-63 MSIR First month of irriga-  
tion when using manage-  
ment option  
64-66 MEIR Last month of irriga-  
tion when using manage-  
ment option

Format (12F5.3, 2I3)

Card This card inputs temperature adjustments in  
8 degrees fahrenheit used in snowmelt calcula-  
tion for the ungaged area; a positive number  
for decrease (see Equation 3.6).

1-10 Identification  
11-15 TMP1(1) Temperature adjustment  
for Subbasin 1  
16-20 TMP1(2) Temperature adjustment  
for Subbasin 2  
.  
.  
.  
TMP1(I) Temperature adjustment  
for Subbasin I

Format (10X, 10F5.2)

## II. Model Indicators and Parameters for each Subbasin

Card 1-8	SBNM(1, L)	Name Subbasin 1 (L is only for the "A" format width)
1		
11-15	IND(1, 1)	Number of different crops in Subbasin 1
16-20	IND(1, 2)	Number of different phreatophytes in Subbasin 1
21-25	IND(1, 3)	Irrigation management indicator (0 or 1) 0 - will divert irrigation water in amount specified in input under VAR(7) 1 - will calculate diversion based on need (will ignore VAR(7) data if it is input)
26-30	IND(1, 4)	Upstream reservoir indicator (0 or 1) 0 - indicates no reservoir in any upstream subbasin 1 - indicates a reservoir in a subbasin upstream from this subbasin Therefore IND(1,4) is always 0 because it is the most upstream subbasin
31-35	IND(1, 5)	Downstream reservoir indicator 0 - no reservoir at the outlet of this subbasin 1 - the subbasin contains a reservoir at its outlet
36-45	AREA(1, 1)	Gaged area of Subbasin 1 in acres (does not include agricultural area)
46-55	AREA(1, 2)	Ungaged area of Subbasin 1 in acres (does not include agricultural area)
56-65	AREA(1, 3)	Scaling area in acres. Consists of total crop area for subbasins with crops. For subbasins with no crop area it is a dummy number



66-75 AREA(1,5) Drainage area of the stream used for ungaged flow correlation, in acres

Format (2A4, 2X, 5I5, 4F10, 0)

Card	1-5	PR(1,1)	PR(1) value for Subbasin 1
2			
	6-10	PR(1,2)	PR(2) value for Subbasin 1
	.	.	.
	.	.	.
	.	.	.
		PR(1,L)	PR(L) value for Subbasin 1

Format (16F5.2)

The value of PR(I, L) comes from the parameter optimization of the subbasin as determined from the parameter optimization program. (See Table A-1 and Table C-2).

If IND(1,5) = 0 skip card 3

Card	1-8	RPR(1,1)	Minimum reservoir storage in acre feet for reservoir in Subbasin 1
3			
	9-16	RPR(1,2)	Lower break point for storage-surface area equation for reservoir in Subbasin 1
	17-24	RPR(1,3)	High break point for storage-surface area equation for reservoir in Subbasin 1
	25-32	RPR(1,4)	Maximum reservoir storage in acre feet for reservoir in Subbasin 1
	33-40	RPR(1,5)	Low range coefficient, $C_1$ , for reservoir in Subbasin 1
	41-48	RPR(1,6)	Low range exponent, $C_2$ , for reservoir in Subbasin 1
	49-56	RPR(1,7)	Intermediate range coefficient, $C_1$ , for reservoir in Subbasin 1
	57-64	RPR(1,8)	Intermediate range exponent, $C_2$ , for reservoir in Subbasin 1
	65-72	RPR(1,9)	High range coefficient, $C_1$ , for reservoir in Subbasin 1
	73-80	RPR(1,10)	High range exponent, $C_2$ , for reservoir in Subbasin 1

Format (4F8.0, 6F8.5)

The relationship, as outlined in the text (Eq. 3.36) gives:

Surface area =  $C_1$  (storage capacity)

As an example, suppose Figure C-1 was for the reservoir in Subbasin 1. Then, from the graph:

RPR(1,2) = 200 acre feet  
RPR(1,3) = 2500 acre feet  
RPR(1,5) = 37 (intercept)  
RPR(1,6) = .570 (slope)  
RPR(1,7) = 370  
RPR(1,8) = .121  
RPR(1,9) = 16  
RPR(1,10) = .531

Card	1-5	SYIC(1,1)	Initial snow storage for Subbasin 1
4			
	6-10	SYIC(1,2)	Initial soil moisture for Subbasin 1 (PR(16) in Table A-1)
	11-15	SYIC(1,3)	Open for use
	16-20	SYIC(1,4)	Initial watershed recharge for Subbasin 1 (PR(18) in Table A-1)
	21-25	SYIC(1,5)	Initial base and groundwater flow for Subbasin 1 (PR(17) in Table A-1)
	26-35	SYIC(1,6)	Initial storage for reservoir in Subbasin 1

Format (5F5.2, F10.0)

SYIC(1,2), SYIC(1,4), and SYIC(1,5) come from parameter optimization.

Card	1-10	Phreatophyte identification
5		
	11-15	CPH(1) $k_c$ for this phreatophyte month 1
	16-20	CPH(2) $k_c$ for this phreatophyte month 2
	.	.
	.	.
	.	.
	66-70	CPH(12) $k_c$ for this phreatophyte month 12
	71-80	APH Acres of this phreatophyte within the subbasin's agricultural area

Format (10X, 12F5.2, F10.0)

This format is repeated for the IND(1,2) phreatophytes in the subbasin.

If IND(1,1) = 0 skip card 6

Card	1-10		Crop Identification
6	11-15	CCR(1)	$k_c$ for this crop month 1
	16-20	CCR(2)	$k_c$ for this crop month 2
	.	.	.
	.	.	.
	.	.	.
	66-70	CCR(12)	$k_c$ for this crop month 12
	71-80	ACR	Acres of this crop within the subbasin's agricultural area

Format (10X, 12F5.2, F10.0)

This format is repeated for the IND(1, 1) crops in the subbasin.

Card	1-5	QDSIR(1, 1)	Desired streamflow at the outlet of Subbasin 1 in cfs for month 1
7			
	6-10	QDSIR(1, 2)	Desired streamflow at the outlet of Subbasin 1 in cfs for month 2
	.	.	.
	.	.	.
	.	.	.
	56-60	QDSIR(1, 12)	Desired streamflow at the outlet of Subbasin 1 in cfs for month 12

Format (12F5.0)

If IND(1, 5) = 0 skip card 8

Card	1-6	SDSIR(1, 1)	Desired storage in acre feet for the reservoir in Subbasin 1 for month 1
8			
	7-12	SDSIR(1, 2)	Desired storage in acre feet for the reservoir in Subbasin 1 for month 2
	.	.	.
	.	.	.
	.	.	.
	67-72	SDSIR(1, 12)	Desired storage in acre feet for the reservoir in Subbasin 1 for month 12

Format (12F6.0)

All of the cards under II are then repeated for Subbasins 2, 3, ..., NSB.

### III. Input Conversion Factors

Card	1-8	CONV(1, 1)	Conversion factor for VAR(1) Subbasin 1
1			
	9-16	CONV(1, 2)	Conversion factor for VAR(2) Subbasin 1
	.	.	.
	.	.	.
	.	.	.

CONV(1, NVR) Conversion factor for VAR(NVR) Subbasin 1

Format (10F8.5)

This format is repeated for Subbasins 2, 3, ..., NSB.

Where:

CONV(I, 1) Converts VAR(1), precipitation data, to inches of water

CONV(I, 2) Converts VAR(2), temperature data, to degrees fahrenheit

The remainder of the CONV(I, L)'s convert the input into inches of water over the agricultural area in acres. If VAR(L) is in acre feet

$CONV(I, L) = 12/AREA(I, 3)$

Card	1-6	CAF(1)	Conversion from inches of water over the agricultural area to acre feet for Subbasin 1
2			
	7-12	CAF(2)	Conversion from inches of water over the agricultural area to acre feet for Subbasin 2

.	.
.	.
.	.

CAF(NSB) Conversion from inches of water over the agricultural area to acre feet for Subbasin NSB

Format (12F6.0)

Where:

CAF(I) is calculated as:

$CAF(I) = AREA(I, 3)/12.$

### IV. Consumptive Use for Open Water

Card	1-10		Card Identification
1			
	11-15	CWS(1)	$k_c$ for open water month 1
	16-20	CWS(2)	$k_c$ for open water month 2
	.	.	.
	.	.	.
	.	.	.
	66-70	CWS(12)	$k_c$ for open water month 12

Format (10X, 12F5.2, F10.0)

# V. Output Formats

Card 1-16 FMT1 Output format 1  
 1 17-32 FMT2 Output format 2  
 .  
 .  
 .  
 49-64 FMT4 Output format 4  
 Format (16A4)

15-20 QCOR(1,2) Correlation streamflow  
 for Subbasin 1 month 2  
 .  
 .  
 .  
 75-80 QCOR(1,12) Correlation streamflow  
 for Subbasin 1 month 12  
 Format (8X, -3P12F6.1)

This card is repeated for Subbasins 2, 3, ..., NSB. This completes one year of correlation stream input. This set is followed by a similar set for year 2, 3, ..., NYR.

# VI. Gaged Flow of the Correlation Streams (in Thousands of Acre Feet)

Card 1-8 Identification  
 1 9-14 QCOR(1,1) Correlation streamflow  
 for Subbasin 1 month 1

VII. The VAR(I, L) and RVAR(I, L) data are read from the tape developed using the data program. Note that the input formats correspond to the formats used to create the tape.

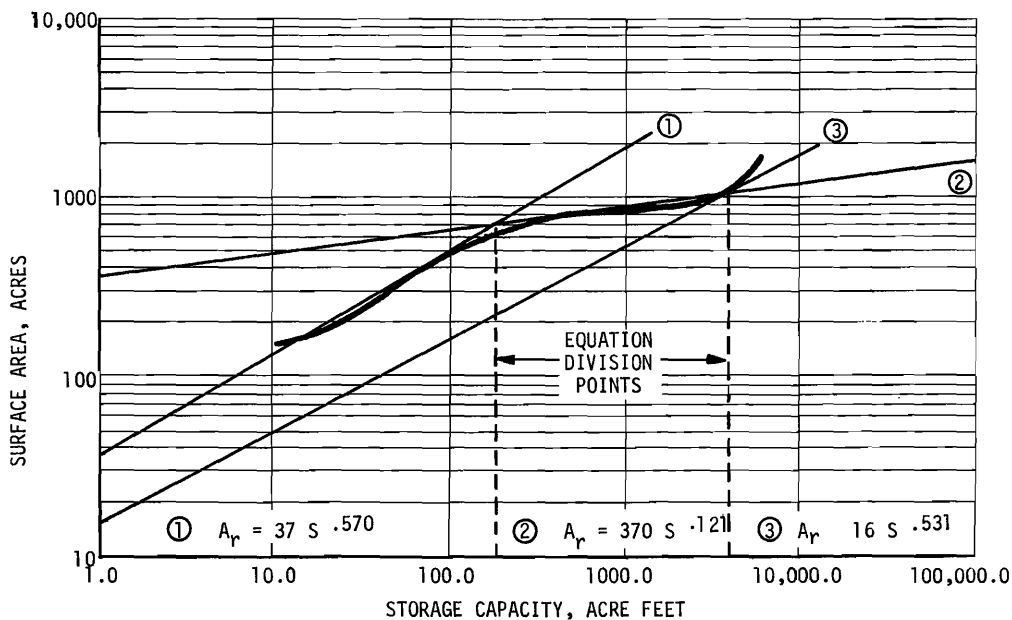
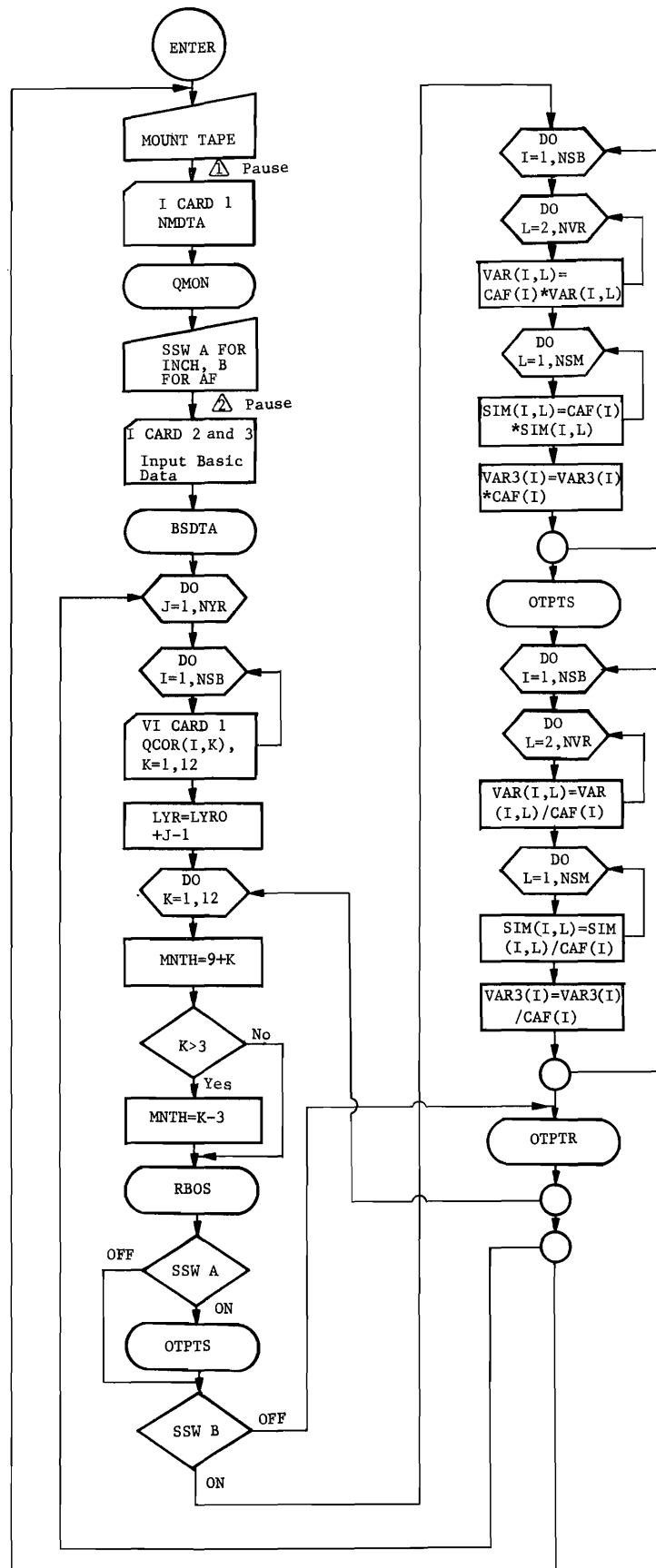
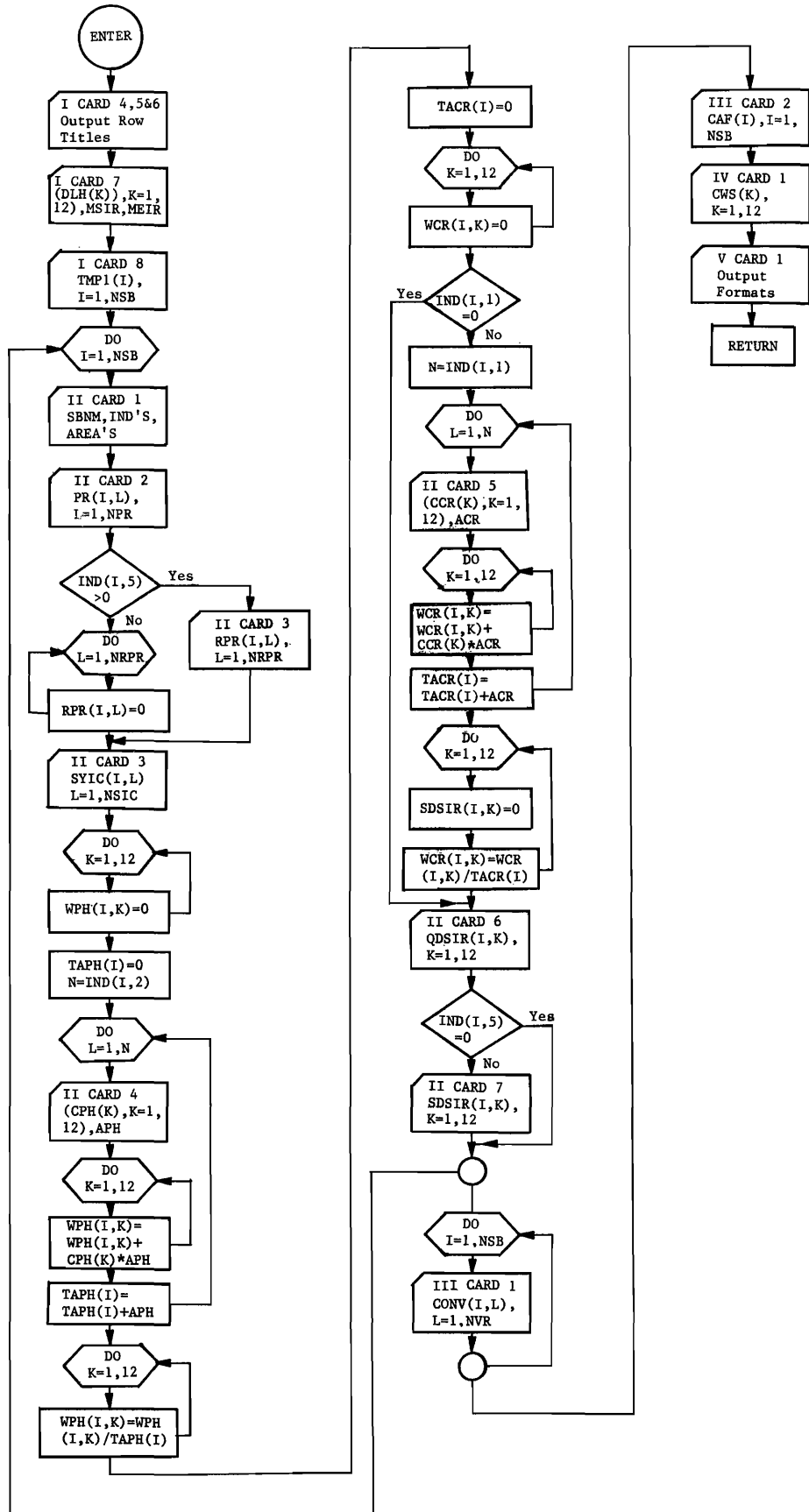
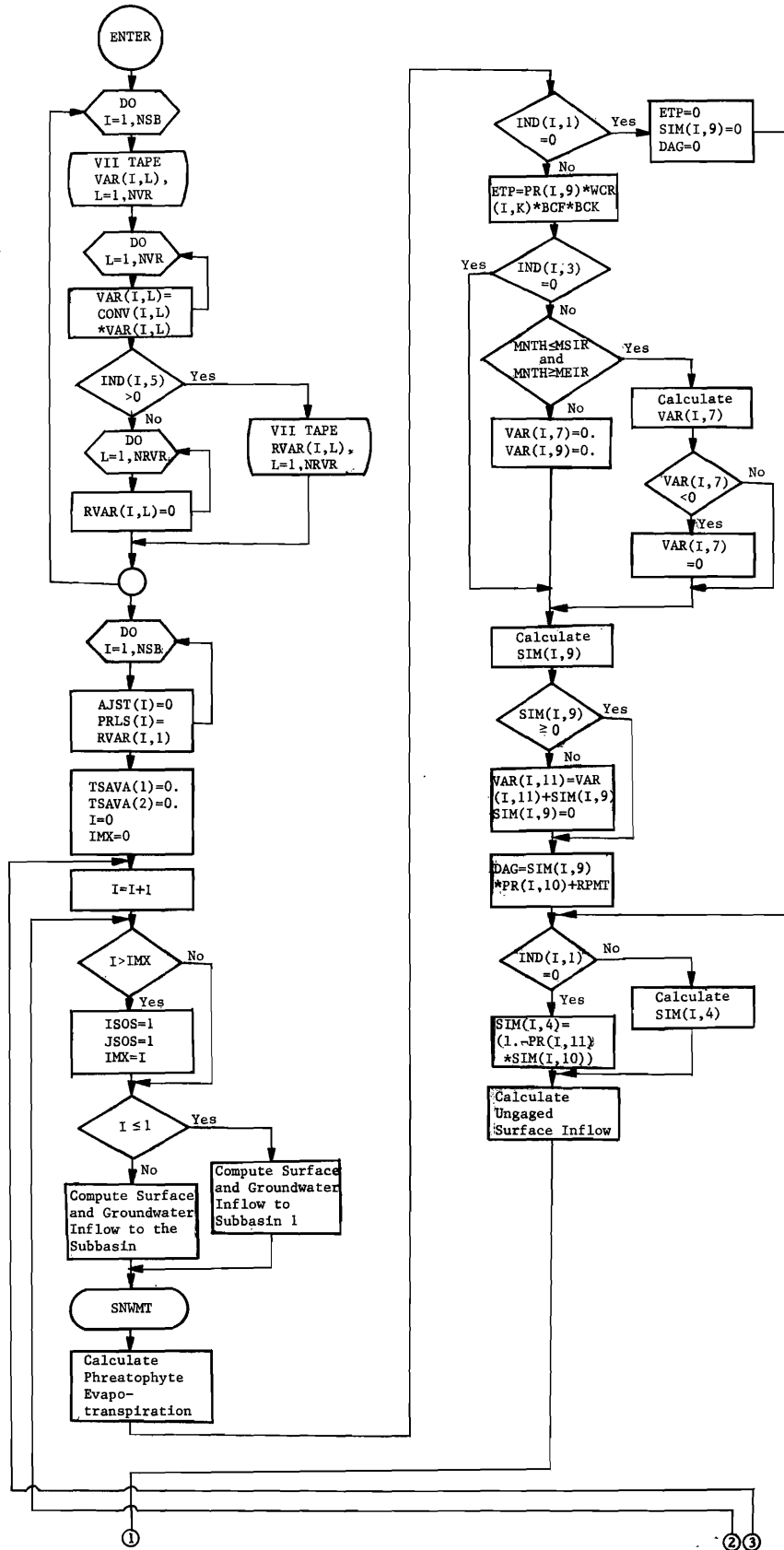


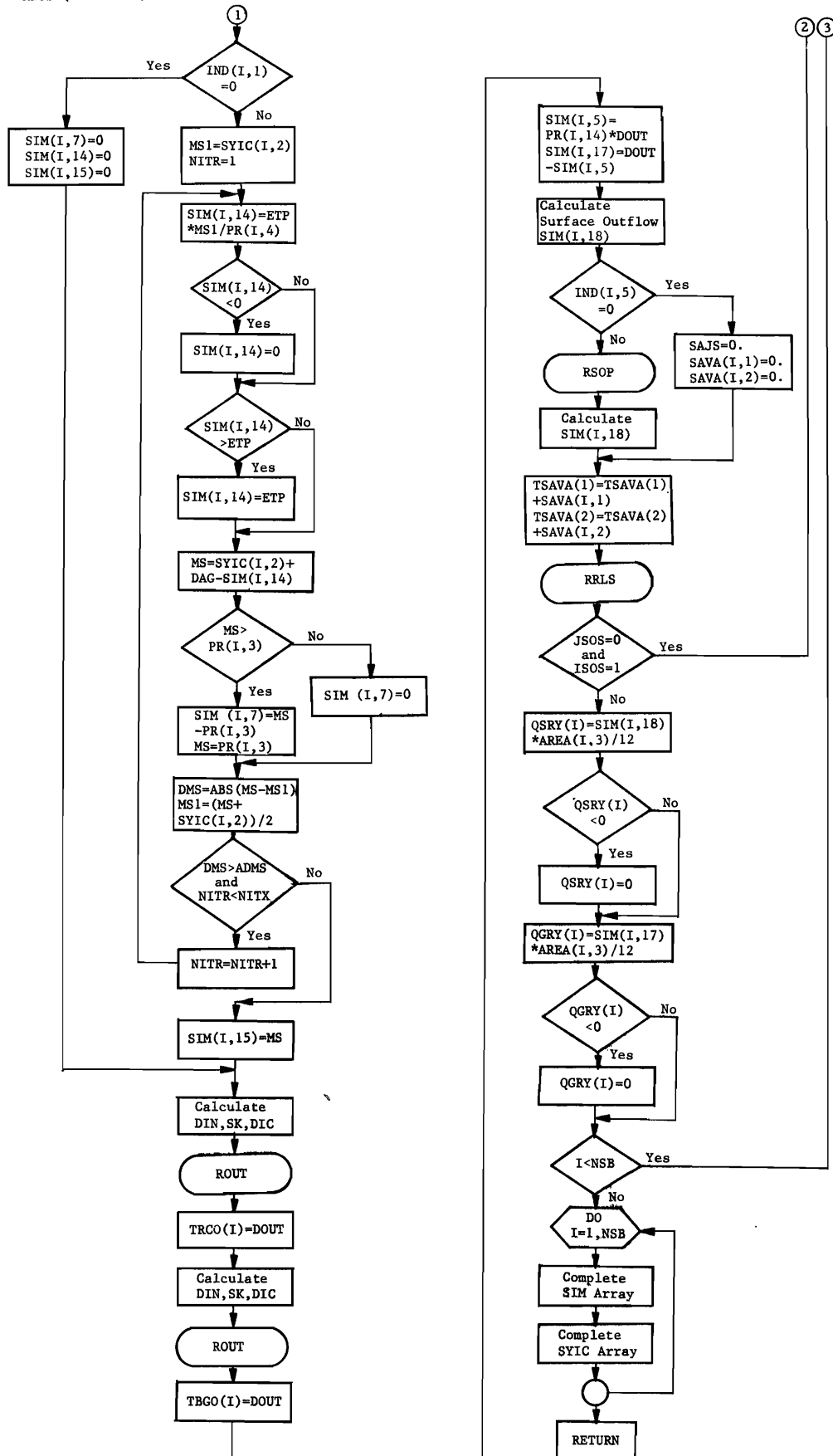
Figure C-1. Reservoir surface area-storage capacity relationship.

MAIN PROGRAM

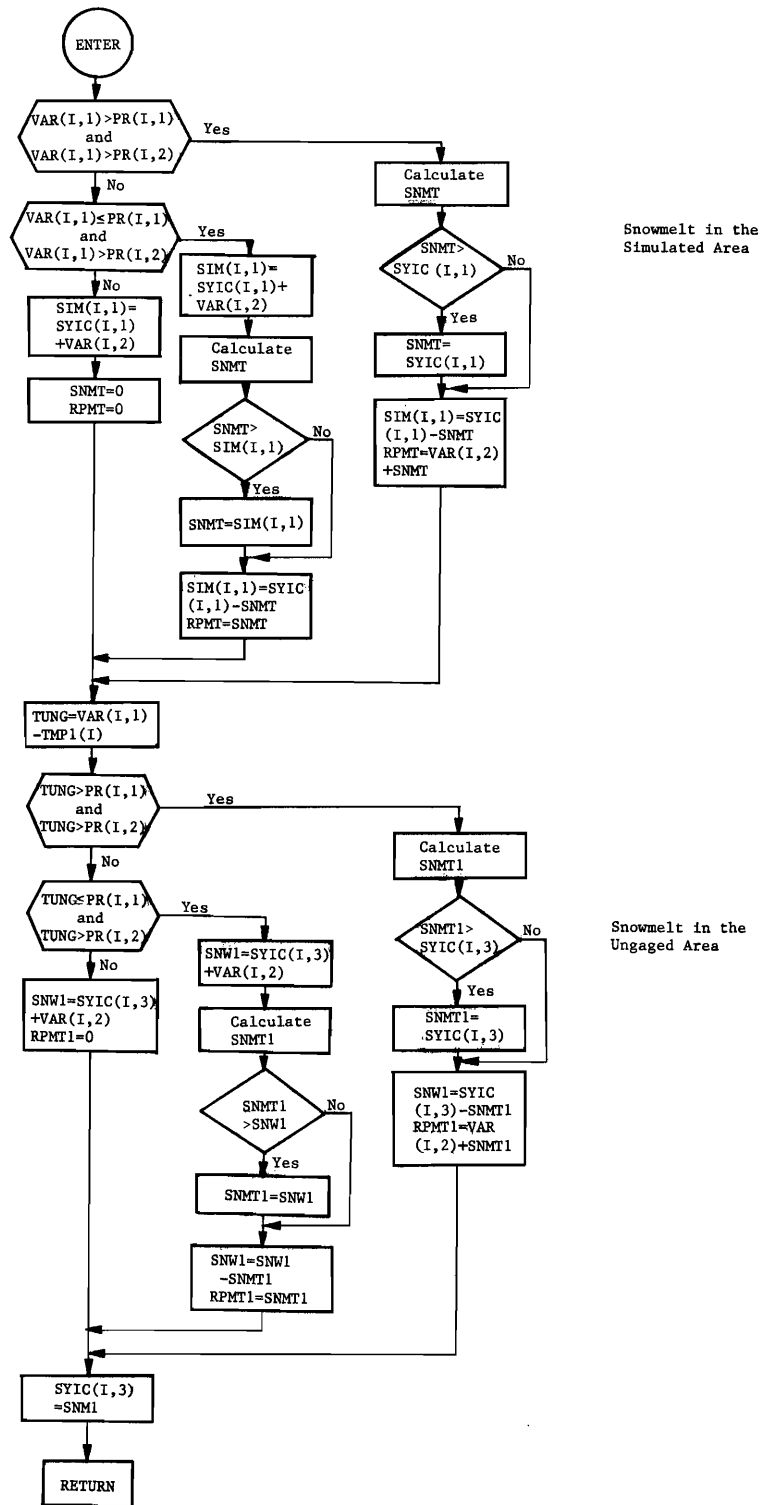








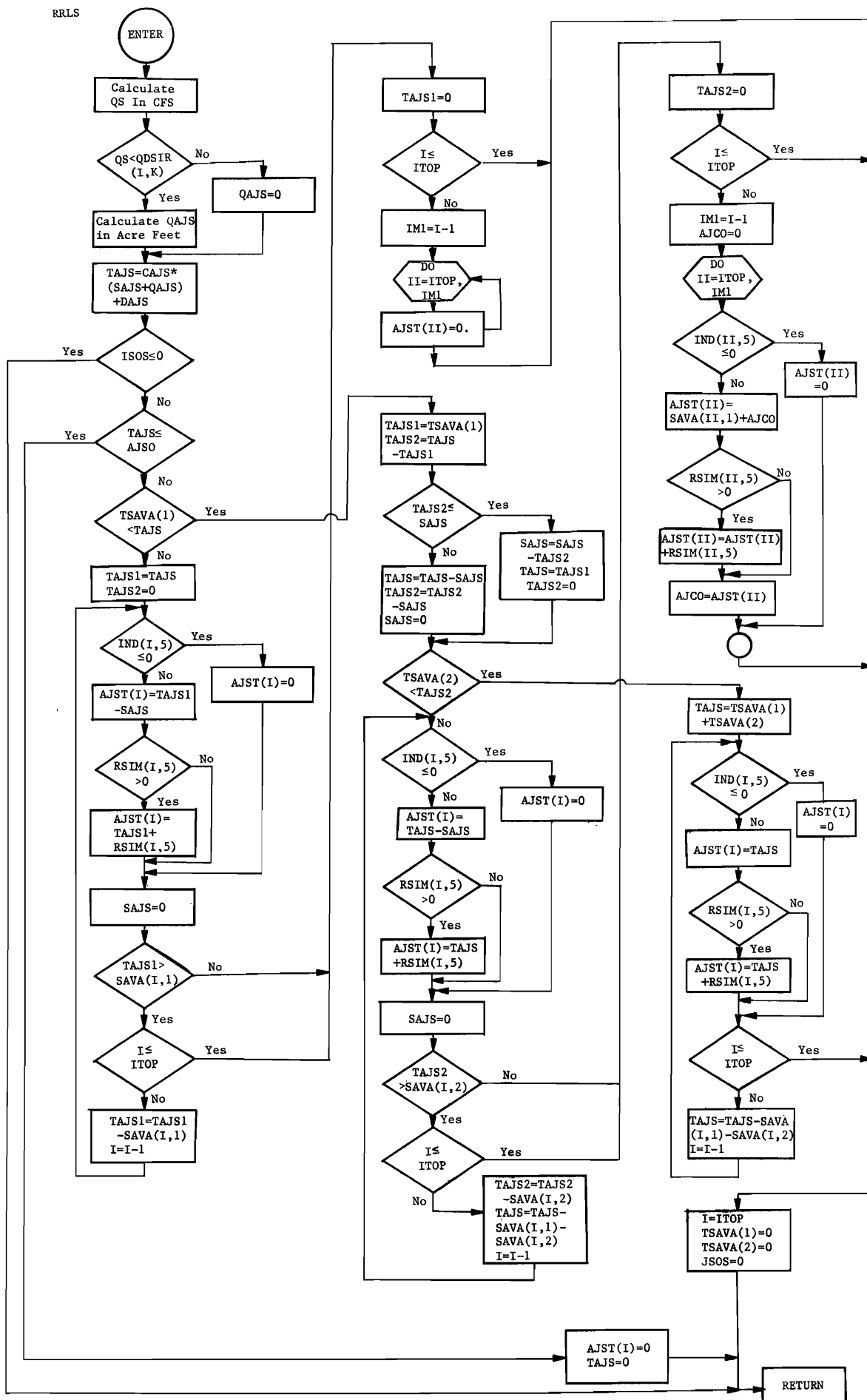
SNWMT

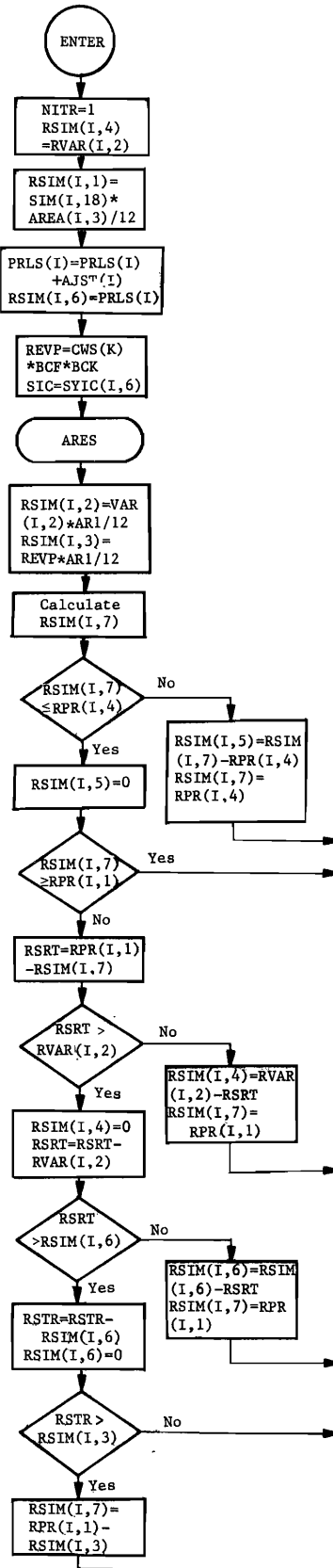


Snowmelt in the  
Simulated Area

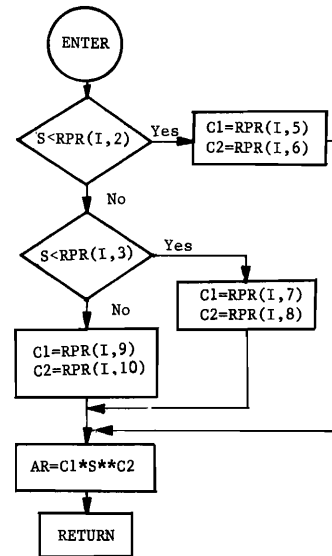
Snowmelt in the  
Ungaged Area







ARES



# RIVER BASIN MANAGEMENT PROGRAM LISTING

```

C   RIVER BASIN OPERATION MODEL
COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
1ACOR(6),   CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSRV(6),GGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
COMMON ACR,ADMS,   AJSO,APH,CAJS,DIC,DIN,DOUT,INI,IN2,IOUT,LYR,
2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
DIMENSION SBNM(4),NMDTA(3)
1 TYPE 199
199 FORMAT(11H MOUNT TAPE/)
OCT 25000
READ(6,99) (NMDTA(I),I=1,3)
99 FORMAT(3A2)
CALL QMDN(21,NMDTA(1),0,13)
C
C   TYPE 202
202 FORMAT(24HSSW A FOR INCH, B FOR AF/)
OCT 25000
C   INPUT BASIC DATA
READ(6,100) (SBNM(II),II=1,4),NSB,NVR,NPR,NSM,NRVR,NRPR,NRSM,NIND,
1NARA,NSIC,LYRO,NYR,INI,IN2,IOUT,NITX,AJSO,ADMS,CAJS,ITOP,DAJS
100 FORMAT(4A4,10I3/I5,5I3,3F5,2,I5,F5.0)
CALL BSDTA
C
C   REPEAT SIMULATION FOR EACH YEAR
DO 26 J=1,NYR
DO 2 I=1,NSB
2 READ(INI,101) (QCOR(I,K),K=1,12)
101 FORMAT(8X,-3P12F6.1)
LYR=LYRO+J-1
C
C   REPEAT SIMULATION FOR EACH MONTH
DO 17 K=1,12
MNTH=9+K
IF(K,GT,3) MNTH=K-3
C
C   SIMULATION OPERATION
CALL RBOS (K)
C
C   IF SSW A ON, OUTPUT MONTHLY HYDROLOGY IN INCHES
OCT 023600
J .10
CALL OTPTS(FMT1,FMT2,K)
C
C   IF SSW B ON, OUTPUT MONTHLY HYDROLOGY IN ACRE-FEET
10 OCT 023500
J .10
C
C   OUTPUT MONTHLY HYDROLOGY IN ACRE-FEET
DO 15 I=1,NSB
DO 13 L=2,NVR
13 VAR(I,L)=CAF(I)*VAR(I,L)
DO 14 L=1,NSM
14 SIM(I,L)=CAF(I)*SIM(I,L)
VAR3(I)=CAF(I)*VAR3(I)
15 CONTINUE
CALL OTPTS(FMT3,FMT4,K)
DO 52 I=1,NSB
DO 50 L=2,NVR
50 VAR(I,L)=VAR(I,L)/CAF(I)
DO 51 L=1,NSM
51 SIM(I,L)=SIM(I,L)/CAF(I)
VAR3(I)=VAR3(I)/CAF(I)
52 CONTINUE
C
C   OUTPUT MONTHLY RESERVOIR OPERATION IN ACRE-FEET
16 CALL DTPR (K)

```

```

17 CONTINUE
26 CONTINUE
J .1
END
C
C   SUBROUTINE FOR BASIC DATA
SUBROUTINE BSDTA
COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
1ACOR(6),   CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSRV(6),GGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
COMMON ACR,ADMS,   AJSO,APH,CAJS,DIC,DIN,DOUT,INI,IN2,IOUT,LYR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
C
C   READ OUTPUT ROW TITLES
READ(INI,100) (OTL(L),L=1,NSM)
READ(INI,100) (ROTL(L),L=1,NRSM)
READ(INI,100) (OTLV(L),L=1,4)
100 FORMAT(20A4)
C
C   READ AND CHECK FRACTION DAY-LIGHT HOURS
READ(INI,101) (DLH(K),K=1,12),MSIR,MEIR
101 FORMAT(12F5,3,2I3)
C
C   INPUT UNGAGED WATERSHED TEMPERATURE ADJUSTMENT
READ(INI,120) (TMP1(I),I=1,NSB)
120 FORMAT(10X,10F5.2)
C
C   INPUT MODEL INDICATORS AND PARAMETERS FOR EACH SUB-BASIN
2 DO 12 I=1,NSB
READ(INI,102) (SBNM(I,L),L=1,2),(IND(I,L),L=1,NIND),(AREA(I,L),L=1
1,NARA)
102 FORMAT(2A4,2X,5I5,4F10.0)
READ(INI,103) (PR(I,L),L=1,NPR)
103 FORMAT(16F5.2)
IF(IND(I,0),GT,0) GO TO 41
DO 40 L=1,NRPR
40 RPR(I,L)=0.
J .42
41 READ(INI,104) (RPR(I,L),L=1,NRPR)
104 FORMAT(4F8.0,6F8.5)
C
C   INPUT INITIAL CONDITIONS
42 READ(INI,105) (SYIC(I,L),L=1,NSIC)
105 FORMAT(5F5.2,F10.0)
C
C   COMPUTE WEIGHTED PHREATOPHYTE AND CROP CONSUMATIVE USE COEFFICIENT
DO 3 K=1,12
3 WPH(I,K)=0.
TAPH(I)=0.
N=IND(I,2)
DO 5 L=1,N
READ(INI,106) (CPH(K),K=1,12),APH
106 FORMAT(10X,12F5.2,F10.0)
DO 4 K=1,12
4 WPH(I,K)=WPH(I,K)+CPH(K)*APH
5 TAPH(I)=TAPH(I)+APH
DO 6 K=1,12
6 WPH(I,K)=WPH(I,K)/TAPH(I)
TACR(I)=0.
DO 7 K=1,12
7 WCR(I,K)=0.
IF(IND(I,1),EQ,0) GO TO 11
N=IND(I,1)
DO 9 L=1,N
READ(INI,106) (CCR(K),K=1,12),ACR
DO 8 K=1,12
8 WCR(I,K)=WCR(I,K)+CCR(K)*ACR
9 TACR(I)=TACR(I)+ACR

```

```

      DO 10 K=1,12
      SDBIR(I,K)=0.
107  MCR(I,K)=MCR(I,K)/TACR(I)
11  READ(IN1,107) (QDSIR(I,K),K=1,12)
      FORMAT(12F5.0)
      IF (IND(I,5).EQ.0) GO TO 12
      READ(IN1,108) (SDBIR(I,K),K=1,12)
108  FORMAT(12F5.0)
12  CONTINUE
C
C  READ AND CHECK CONVERSION FACTORS
      DO 20 I=1,N8B
      READ(IN1,109) (CONV(I,L),L=1,NVR)
109  FORMAT(10F5.5)
20  CONTINUE
      READ(6,108) (CAF(I),I=1,N8B)
C
C  READ CONSUMPTIVE USE COEFFICIENT FO OPEN WATER
      READ(IN1,108) (CWS(K),K=1,12)
C
C  READ OUTPUT FORMAT
      READ(IN1,110) (FMT1(L),L=1,4), (FMT2(L),L=1,4), (FMT3(L),L=1,4),
110  (FMT4(L),L=1,4)
      FORMAT(10A4)
      RETURN
      END

```

```

C
C  SUBROUTINE FOR OPERATION STUDY
C  SUBROUTINE RBDS (K)
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
1ACOR(6), CAP(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
2IND(6,8),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
3RPR(6,10),RVAR(6,12),SBNH(6,2),SDBIR(6,12),SIM(6,18),SYIC(6,8),
4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QGRY(6),GGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
      COMMON ACR,ADMS, AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
1HEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,N8B,N8M,NVR,
2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
      DIMENSION TRCO(7),TBGO(7)
      REAL MS1,MS
C  INPUT COMPILED OBSERVED DATA FOR EACH SUB-BASIN
      DO 3 I=1,N8B
      READ(IN2,100) (VAR(I,L),L=1,NVR)
100  FORMAT(2F8.3,5F8.0/10F8.0)
      DO 2 L=1,NVR
      2  VAR(I,L)=CONV(I,L)*VAR(I,L)
      IF (IND(I,5).GT.0) GO TO 51
      DO 50 L=1,NRVR
      RVAR(I,L)=0.
50  J=.3
51  READ(IN2,101) (RVAR(I,L),L=1,NRVR)
101  FORMAT(10F8.0)
3  CONTINUE
      DO 47 I=1,N8B
      AJST(I)=0.
47  PRLS(I)=RVAR(I,1)
      TSAVA(1)=0.
      TSAVA(2)=0.
      I=0
      IMX=0
4  I=I+1
44  IF (I.GT.IMX) GO TO 60
      J=.61
60  ISOS=1
      JSOS=1
      IMX=I
61  IF (I.LE.1) GO TO 49
      VAR3(I)=VAR(I,3)+QGRY(I-1)*12./AREA(I,3)
      VAR4(I)=VAR(I,4)+GGRY(I-1)*12./AREA(I,3)
      J
52
49  VAR3(I)=VAR(I,3)
      VAR4(I)=VAR(I,4)

```

```

C  SNOW STORAGE AND SNOWMELT
52 CALL SNWMT (I,RPMT,RPMT1)
C
C  PHREATOPHYTE EVAPOTRANSPIRATION
      BCF=VAR(I,1)+DLH(K)
      BCK=.0173+VAR(I,1)-.314
      IF (BCK.LT..3) BCK=.3
      SIM(I,13)=PR(I,9)+WPH(I,K)+BCF*BCK+TAPH(I)/AREA(I,3)
C
C  CROP POTENTIAL EVAPOTRANSPIRATION AND WATER SUPPLIES
      IF (IND(I,1).EQ.0) GO TO 18
      ETP=PR(I,9)+MCR(I,K)+BCF*BCK
      IF (IND(I,3).EQ.0) GO TO 9
      IF (MNTH,GE,MSIR,AND,MNTH,LE,MEIR) GO TO 8
      VAR(I,7)=0.
      VAR(I,9)=0.
      J=.9
      8  VAR(I,7)=ETP/PR(I,10)-(RPMT+VAR(I,5)+VAR(I,9)-VAR(I,11))
      IF (VAR(I,7).LT.0.) VAR(I,7)=0.
      9  SIM(I,9)=VAR(I,5)+VAR(I,7)+VAR(I,9)-VAR(I,11)
      IF (SIM(I,9).GE.0.) GO TO 78
      VAR(I,11)=VAR(I,11)+SIM(I,9)
      SIM(I,9)=0.
78  DAG=SIM(I,9)+PR(I,10)+RPMT
      J=.11
10  ETP=0.
      SIM(I,9)=0.
      DAG=0.
11  SIM(I,18)=VAR(I,6)+VAR(I,8)+VAR(I,10)=VAR(I,12)
C
C  RETURN FLOW
      IF (IND(I,1).EQ.0) GO TO 12
      SIM(I,4)=(1.-PR(I,10))*SIM(I,9)+(1.-PR(I,11))*SIM(I,18)
      J=.13
12  SIM(I,4)=(1.-PR(I,11))*SIM(I,18)
C
C  UNGAGED SURFACE INFLOW
13  SIM(I,2)=PR(I,5)+AREA(I,2)/AREA(I,4)+QCOR(I,K)*12./AREA(I,3)+
1PR(I,12)+RPMT1*AREA(I,2)/AREA(I,3)+PR(I,13)*(AREA(I,1)+AREA(I,2))/
2AREA(I,3)
C
C  EVAPOTRANSPIRATION, SOIL MOISTURE, AND PERCOLATION
      IF (IND(I,1).EQ.0) GO TO 19
      MS1=SYIC(I,2)
      NITR=1
14  SIM(I,14)=ETP+MS1/PR(I,4)
      IF (SIM(I,14).LT.0.) SIM(I,14)=0.
      IF (SIM(I,14).GT.ETP) SIM(I,14)=ETP
      MS=SYIC(I,2)+DAG=SIM(I,14)
      IF (MS.GT.PR(I,3)) GO TO 15
      SIM(I,7)=0.
      J=.16
15  SIM(I,7)=MS=PR(I,3)
      MS=PR(I,3)
16  DMS=ABS(MS-MS1)
      MS1=(MS+SYIC(I,2))/2.
      IF (DMS.GT.ADMS,AND,NITR,LT,NITX) GO TO 17
      J=.18
17  NITR=NITR+1
      J=.14
18  SIM(I,15)=MS
      J=.20
19  SIM(I,7)=0.
      SIM(I,14)=0.
      SIM(I,15)=0.
C
C  GROUNDWATER RECHARGE AND OUTFLOW
20  DIN=PR(I,15)+RPMT*(AREA(I,1)+AREA(I,2))/AREA(I,3)
      SK=PR(I,6)
      DIC=SYIC(I,4)
      CALL ROUT
      TRCO(I)=DOUT
      DIN=VAR4(I)+DOUT+SIM(I,7)-VAR(I,9)-VAR(I,10)

```

```

SK=PR(I,7)
DIC=SYIC(I,5)
CALL ROUT
TBGO(I)=DOUT
SIM(I,5)=PR(I,14)*DOUT
SIM(I,17)=DOUT-SIM(I,5)

C
C SURFACE OUTFLOW
21 SIM(I,18)=VAR3(I) +SIM(I,2)+SIM(I,4)+SIM(I,5)-VAR(I,7)-VAR(I,8)-
  1SIM(I,13)+RPMT+TAPH(I)/AREA(I,3)

C
C RESERVOIR OPERATION
IF(IND(I,5).EQ.0) GO TO 22
CALL RSOP (K,I,JSOS)
SIM(I,18)=(RSIM(I,5)+RSIM(I,6))*12./AREA(I,3)
J .23
22 SAJS=0.
  SAVA(I,1)=0.
  SAVA(I,2)=0.
23 TSAVA(1)=TSAVA(1)+SAVA(I,1)
  TSAVA(2)=TSAVA(2)+SAVA(I,2)
  CALL RRLS(I,K,JSOS)
  IF(JSOS.EQ.0.AND.ISOS.EQ.1) GO TO 44
40 QSR(I)=SIM(I,18)*AREA(I,3)/12.
  IF(QSR(I).LT.0.) QSR(I)=0.
  QGR(I)=SIM(I,17)*AREA(I,3)/12.
  IF(QGR(I).LT.0.) QGR(I)=0.
  IF(I.LT.NSB) GO TO 4

C
C COMPLETE SIM ARRAY
DO 39 I=1,NSB
  SIM(I,3)=VAR(I,5)+VAR(I,6)
  SIM(I,6)=VAR(I,9)+VAR(I,10)
  SIM(I,8)=VAR4(I)
  SIM(I,11)=VAR(I,11)+VAR(I,12)
  IF(IND(I,5).GE.1) SIM(I,11)=VAR(I,11)+VAR(I,12)+RSIM(I,4)*12./
    1AREA(I,3)
  SIM(I,12)=QDSIR(I,K)*1.98*30.*12./AREA(I,3)-SIM(I,18)
  IF(SIM(I,12).LT.0.) SIM(I,12)=0.
  SIM(I,16)=SIM(I,17)+SIM(I,18)

C
C RESET INITIAL VALUES
SYIC(I,1)=SIM(I,1)
SYIC(I,2)=SIM(I,18)
SYIC(I,4)=TRCO(I)
SYIC(I,5)=TBGO(I)
IF(IND(I,5).EQ.1) SYIC(I,6)=RSIM(I,7)
39 CONTINUE
RETURN
END

C
C SUBROUTINE FOR SNOW MELT
SUBROUTINE SNMNT (I,RPMT,RPMT1)
COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
1ACOR(6), CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSR(6),QGR(6),SAVA(6,2),PRLS(6),TSAVA(2)
COMMON ACR,ADMS, AJSO,APH,CAJS,DIC,DIN,DOUT,INI,IN2,IOUT,LYR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
52 IF(VAR(I,1).GT.PR(I,1).AND.VAR(I,1).GT.PR(I,2)) GO TO 6
  IF(VAR(I,1).LE.PR(I,1).AND.VAR(I,1).GT.PR(I,2)) GO TO 5
  SIM(I,1)=SYIC(I,1)+VAR(I,2)
  SNMT=0.
  RPMT=0.
  J .7
5 SIM(I,1)=SYIC(I,1)+VAR(I,2)
  SNMT=SIM(I,1)*(1.-EXP(-PR(I,8)*(VAR(I,1)-PR(I,2))))
  IF(SNMT.GT.SIM(I,1)) SNMT=SIM(I,1)
  SIM(I,1)=SIM(I,1)-SNMT
  RPMT=SNMT
  J .7

```

```

6 SNMT=SYIC(I,1)*(1.-EXP(-PR(I,8)*(VAR(I,1)-PR(I,2))))
  IF(SNMT.GT.SYIC(I,1)) SNMT=SYIC(I,1)
  SIM(I,1)=SYIC(I,1)-SNMT
  RPMT=VAR(I,2)+SNMT
7 TUNG=VAR(I,1)-TMP1(I)
  IF(TUNG.GT.PR(I,1).AND.TUNG.GT.PR(I,2)) GO TO 41
  IF(TUNG.LE.PR(I,1).AND.TUNG.GT.PR(I,2)) GO TO 90
  SNW1=SYIC(I,3)+VAR(I,2)
  RPMT1=0.
  J .42
90 SNW1=SYIC(I,3)+VAR(I,2)
  SNMT1=SNW1*(1.-EXP(-PR(I,8)*(TUNG=PR(I,2))))
  IF(SNMT1.GT.SNW1) SNMT1=SNW1
  SNW1=SNW1-SNMT1
  RPMT1=SNMT1
  J .42
41 SNMT1=SYIC(I,3)*(1.-EXP(-PR(I,8)*(TUNG=PR(I,2))))
  IF(SNMT1.GT.SYIC(I,3)) SNMT1=SYIC(I,3)
  SNW1=SYIC(I,3)-SNMT1
  RPMT1=VAR(I,2)+SNMT1
42 SYIC(I,3)=SNW1
  RETURN
END

C
C SUBROUTINE FOR RESERVOIR RELEASE ADJUSTMENTS
SUBROUTINE RRLS(I,K,JSOS)
COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
1ACOR(6), CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSR(6),QGR(6),SAVA(6,2),PRLS(6),TSAVA(2)
COMMON ACR,ADMS, AJSO,APH,CAJS,DIC,DIN,DOUT,INI,IN2,IOUT,LYR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS

C
C CHECK FOR DESIRABLE FLOW AND ADJUST RESERVOIR RELEASE
QS=SIM(I,18)*AREA(I,3)/(12.*30.*1.98)
IF(QS.LT.QDSIR(I,K)) GO TO 24
QAJ=0.
J .25
24 QAJ=(QDSIR(I,K)-QS)*1.98*30.
25 TAJS=CAJS*(SAJS+QAJ)+DAJS
  IF(ISOS.LE.0) GO TO 38
  IF(TAJS.LE.AJSO) GO TO 42
  IF(TSAVA(1).LT.TAJS) GO TO 38

C
C SUFFICIENT WATER AVAILABLE IN RESERVOIRS
TAJS1=TAJS
TAJS2=0.
40 IF(IND(I,5).LE.0) GO TO 41
  AJST(I)=TAJS1-SAJS
  IF(RSIM(I,5).GT.0.) AJST(I)=TAJS1+RSIM(I,5)
  J .44
41 AJST(I)=0.
44 SAJS=0.
45 IF(TAJS1.GT.SAVA(I,1)) GO TO 50
  J .28
50 IF(I.LE.ITOP) GO TO 28
  TAJS1=TAJS1-SAVA(I,1)
  I=I-1
  J .40
28 TAJS1=0.
  IF(I.LE.ITOP) GO TO 37
  IM=I-1
  DO 29 II=ITOP,IM
29 AJST(II)=0.
  J .37

C
C STORAGE LESS THAN DESIRABLE IN SOME OR ALL RESERVOIRS
30 TAJS1=TSAVA(1)
  TAJS2=TAJS-TAJS1
  IF(TAJS2.LE.SAJS) GO TO 90
  TAJS=TAJS-SAJS

```

```

      TAJ52=TAJS2-SAJS
      SAJS=0.
      J =.91
96  SAJS=8AJS-TAJ52
      TAJ5=TAJS1
      TAJ52=0.
91  IF (TSAVA(2).LT.TAJ52) GO TO 35
99  IF (IND(I,5).LE.0) GO TO 61
      AJST(I)=TAJS-SAJS
      IF (RSIM(I,5).GT.0.) AJST(I)=TAJS+RSIM(I,5)
      J =.65
61  AJST(I)=0.
65  SAJS=0.
68  IF (TAJS2.GT.SAVA(I,2)) GO TO 51
      J =.33
51  IF (I.LE.ITOP) GO TO 33
      TAJ52=TAJS2-SAVA(I,2)
      TAJ5=TAJS-SAVA(I,1)-SAVA(I,2)
      I=I-1
      J =.59
33  TAJ52=0.
      IF (I.LE.ITOP) GO TO 37
      IM1=I-1
      AJCO=0.
      DO 34 II=ITOP,IM1
      IF (IND(II,5).LE.0) GO TO 88
      AJST(II)=SAVA(II,1)+AJCO
      IF (RSIM(II,5).GT.0.) AJST(II)=AJST(II)+RSIM(II,5)
      AJCO=AJST(II)
      J =.34
88  AJST(II)=0.
34  CONTINUE
      J =.57
C
C      STORAGE LESS THAN MINIMUM IN SOME OR ALL RESERVOIRS
35  TAJ5=TSAVA(1)+TSAVA(2)
78  IF (IND(I,5).LE.0) GO TO 71
      AJST(I)=TAJS
      IF (RSIM(I,5).GT.0.) AJST(I)=TAJS+RSIM(I,5)
      J =.72
71  AJST(I)=0.
72  IF (I.LE.ITOP) GO TO 37
      TAJ5=TAJS-SAVA(I,1)-SAVA(I,2)
      I=I-1
      J =.70
37  I=ITOP
      TSAVA(1)=0.
      TSAVA(2)=0.
      JSOS=0
      J =.38
42  AJST(I)=0.
      TAJ5=0.
38  RETURN
      END
C
C      SUBROUTINE FOR LINEAR RESERVOIR ROUTING
      SUBROUTINE ROUT
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
      1ACOR(6), CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
      2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
      3RPR(6,18),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
      4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
      5FMT3(4),FMT4(4),QSRV(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2),
      COMMON ACR,ADMS, AJSD,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
      1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSH,NRVR,NSIC,NSB,NSM,NVR,
      2NVR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
      DOUT=DIN*(DIC-DIN)*EXP(-1./SK)
      RETURN
      END

```

```

C      SUBROUTINE FOR RESERVOIR OPERATION
      SUBROUTINE RSOP (K,I,JSOS)
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
      1ACOR(6), CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
      2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
      3RPR(6,18),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),
      4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
      5FMT3(4),FMT4(4),QSRV(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2),
      COMMON ACR,ADMS, AJSD,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
      1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSH,NRVR,NSIC,NSB,NSM,NVR,
      2NVR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
      NITR=1
      RSIM(I,4)=RVAR(I,2)
C
C      RESERVOIR INFLOW
      RSIM(I,1)=SIM(I,18)+AREA(I,3)/12.
C
C      RESERVOIR RELEASE
      PRLS(I)=PRLS(I)+AJST(I)
      RSIM(I,6)=PRLS(I)
C
C      RESERVOIR EVAPORATION
      REVP=CWS(K)+BCF*BCK
      SIC=SYIC(I,6)
      CALL ARE3(SIC,AR1,I)
      1 RSIM(I,2)=VAR(I,2)+AR1/12.
      RSIM(I,3)=REVP+AR1/12.
C
C      RESERVOIR STORAGE
      RSIM(I,7)=SIC+RSIM(I,1)+RSIM(I,2)-RSIM(I,3)-RSIM(I,4)-RSIM(I,6)
C
C      SPILL FLOW
      IF (RSIM(I,7).LE.RPR(I,4)) GO TO 2
      RSIM(I,5)=RSIM(I,7)-RPR(I,4)
      RSIM(I,7)=RPR(I,4)
      J =.6
      2 RSIM(I,5)=0.
      IF (RSIM(I,7).GE.RPR(I,1)) GO TO 6
      RSRT=RPR(I,1)-RSIM(I,7)
      IF (RSRT.GT.RVAR(I,2)) GO TO 3
      RSIM(I,4)=RVAR(I,2)-RSRT
      RSIM(I,7)=RPR(I,1)
      J =.6
      3 RSIM(I,4)=0.
      RSRT=RSRT-RVAR(I,2)
      IF (RSRT.GT.RSIM(I,6)) GO TO 4
      RSIM(I,6)=RSIM(I,6)-RSRT
      RSIM(I,7)=RPR(I,1)
      J =.6
      4 RSRT=RSRT-RSIM(I,6)
      RSIM(I,6)=0.
      IF (RSRT.GT.RSIM(I,3)) GO TO 5
      RSIM(I,7)=RPR(I,1)-RSRT
      J =.6
      5 RSIM(I,7)=RPR(I,1)-RSIM(I,3)
C
C      CHECK FOR AVAILABLE AND DESIRABLE STORAGES
      6 SAVA(I,1)=RSIM(I,7)-SDSIR(I,K)
      IF (SAVA(I,1).LT.0.) SAVA(I,1)=0.
      SAVA(I,2)=RSIM(I,7)-RPR(I,1)-SAVA(I,1)
      IF (SAVA(I,2).LT.0.) SAVA(I,2)=0.
      IF (RSIM(I,7).LT.SDSIR(I,K)) GO TO 8
      SAJS=0.
      J =.9
      8 SAJS=SDSIR(I,K)-RSIM(I,7)
      9 IF (JSOS.EQ.0) ISOS=0
      RETURN
      END
C
C      SUBROUTINE FOR RESERVOIR WATER SURFACE AREA
      SUBROUTINE ARE3(S,AR,I)
      COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
      1ACOR(6), CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
      2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
      3RPR(6,18),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,18),SYIC(6,6),

```

```

4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSR(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
COMMON ACR,ADMS, AJSO,APH,CAJS,DIC,DIN,DOU,INI,IN2,IOUT,LYR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
IF(S,L,RPR(I,2)) GO TO 2
IF(S,L,RPR(I,3)) GO TO 1
C1=RPR(I,9)
C2=RPR(I,10)
J .3
1 C1=RPR(I,7)
C2=RPR(I,8)
J .3
2 C1=RPR(I,5)
C2=RPR(I,6)
3 AR=C1+S**C2
RETURN
END

```

```

C
C SUBROUTINE FOR OUTPUT SIMULATED HYDROLOGY
SUBROUTINE OTPTS(FMTA,FMTB,K)
COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
1ACOR(6), CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,10),SYIC(6,6),
4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSR(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
COMMON ACR,ADMS, AJSO,APH,CAJS,DIC,DIN,DOU,INI,IN2,IOUT,LYR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
DIMENSION FMTA(4),FMTB(4)
IF(MNTH,EQ,0) GO TO 1
WRITE(IOUT,200) L,YR,K
200 FORMAT(//1X,3HL =,I5,5X,3HK =,I3)
J .2
1 WRITE(IOUT,201) L,YR
201 FORMAT(//1X,3HL =,I5,2X,6HANNUAL)
2 WRITE(IOUT,202) ((SBNM(I,L),L=1,2),I=1,NSB)
202 FORMAT(//7H ITEM ,9(1X,2A4))
WRITE(IOUT,FMTA) OTLV(1),(VAR(I,1),I=1,NSB)
WRITE(IOUT,FMTB) OTLV(2),(VAR(I,2),I=1,NSB)
WRITE(IOUT,FMTB) OTL(1),(SIM(I,1),I=1,NSB)
WRITE(IOUT,FMTB) OTLV(3),(VAR3(I),I=1,NSB)
DO 4 L=2,NSM
4 WRITE(IOUT,FMTB) OTL(L),(SIM(I,L),I=1,NSB)
WRITE(IOUT,FMTB) OTLV(4),(VAR(I,13),I=1,NSB)
RETURN
END

```

```

C
C SUBROUTINE FOR OUTPUT RESERVOIR OPERATION
SUBROUTINE OTPTR(K)
COMMON AJST(6),AREA(6,4),QCOR(6,12),TMP1(6),VAR3(6),VAR4(6),
1ACOR(6), CAF(6),CCR(12),CONV(6,13),CPH(12),CWS(12),DLH(12),
2IND(6,5),OTL(19),OTLV(4),PR(6,15),QDSIR(6,12),RSIM(6,7),ROTL(7),
3RPR(6,10),RVAR(6,12),SBNM(6,2),SDSIR(6,12),SIM(6,10),SYIC(6,6),
4TACR(6),TAPH(6),VAR(6,13),WCR(6,12),WPH(6,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSR(6),QGRY(6),SAVA(6,2),PRLS(6),TSAVA(2)
COMMON ACR,ADMS, AJSO,APH,CAJS,DIC,DIN,DOU,INI,IN2,IOUT,LYR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
2NYR,SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS
NRS=0
DO 1 I=1,NSB
1 NRS=NRS+IND(I,5)
IF(NRS,EQ,0) GO TO 4
WRITE(IOUT,200)
200 FORMAT(//1X,9HRESERVOIR)
WRITE(IOUT,202) (ROTL(L),L=1,NRSH)
202 FORMAT(//9H SUB BSN,7(3XA4),4X,4HAJST)
DO 3 I=1,NSB
IF(IND(I,5),EQ,0) GO TO 3
WRITE(IOUT,203) (SBNM(I,L),L=1,2),(RSIM(I,L),L=1,NRSH),AJST(I)
203 FORMAT(1X,2A4,7F9.0,F8.0)
3 CONTINUE
4 RETURN
END

```

## SAMPLE INPUT

### I. BASIC DATA

```

CARD 1
OBDT42
CARD 2
PROVO R. BASIN 3 13 15 18 2 10 7 5 4 6
CARD 3
1950 20 6 13 6 20 2000 10 100 2 0
CARD 4
SNOWGUNGQIMPQRTNOBSEGWELQPRCQGWIQIRROMNIQEXQSRTEYPMHETCRSLMSQTOTQGWQSQOTQDEV
CARD 5
ROINRPTREVPRDIVRSPLRLSRSTR
CARD 6
TEMPPRCPOGINOGOT
CARD 7
.077 .067 .065 .067 .067 .083 .089 .100 .121 .102 .096 .084 4 10
CARD 8
TMP1 5.2 5.2 7.9

```

### II. MODEL INDICATORS AND PARAMETERS FOR EACH SUBBASIN

```

CARD 1
FRANCIS 4 4 0 0 0 21376 109056 3329 104320
CARD 2
4000 3000 600 400 20 20 40 12 100 30 80 04 12 40 02
CARD 3
IND(1,5)=0 SKIP CARD 3 FOR THIS SUBBASIN
CARD 4
00 400 100 300 400
CARD 5
C2 HMGW 2 125 102 75 65 80 113 136 141 142 142 141 136 1
C3 MWGT 3 81 76 69 56 53 53 55 61 68 77 82 83 930
C4 LWGT 4 50 47 42 35 33 33 34 38 42 48 51 51 19
C5 OPWT 5 137 128 112 101 130 149 156 155 151 144 141 138 1
CARD 6
A1 ALPA 1 90 79 65 63 74 86 99 112 119 110 105 99 1389
A2 PAST 2 80 74 58 55 66 81 86 102 99 93 91 87 924
A3 ADHA 3 84 77 62 55 66 81 94 109 115 110 105 95 490
A4 SMGR 4 22 29 29 29 29 28 74 118 127 73 40 19 326
CARD 7 (NOTE- THE FLOW IS SET NEGATIVE SO THAT ACTUAL SIMULATIONS ARE OUTPUT
WITH NO ADJUSTMENT BY THE RESERVOIR.)
-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999
CARD 8
IND(1,5)=0 SKIP CARD 8 FOR THIS SUBBASIN

```

### REPEAT CARDS UNDER II. FOR REMAINING SUBBASINS

```

A 2,3 7 4 0 0 1 19200 190413 16531 104320
3200 2600 1000 400 05 80 100 18 110 50 80 02 20 40 05
-999999 9500 111000 9999999 1.85 .6249 4.58 .528 .187 .8816
00 400 100 200 200
C2 HMGW 2 125 102 75 65 80 113 136 141 142 142 141 136 191
C3 MWGT 3 81 76 69 56 53 53 55 61 68 77 82 83 410
C4 LWGT 4 50 47 42 35 33 33 34 38 42 48 51 51 2133
C5 OPWT 5 137 128 112 101 130 149 156 155 151 144 141 138 49
A1 ALPA 1 90 79 65 63 74 86 99 112 119 110 105 99 6794
A2 PAST 2 80 74 58 55 66 81 86 102 99 93 91 87 5428
A3 ADHA 3 84 77 62 55 66 81 94 109 115 110 105 95 1970
A4 SMGR 4 22 29 29 29 29 28 74 118 127 73 40 19 1739
A5 CORN 5 99 29 29 29 29 28 74 118 127 73 40 19 30
A12 IDLE12 35 30 25 25 25 30 33 38 39 39 39 39 533
A13 BEAN13 25 29 29 29 29 28 22 67 111 89 75 20 37
-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999-9999
80000 80000 80000 80000 80000 80000 80000 80000 80000 80000 80000 80000
A456 12 5 0 1 0 0 0 54487 18959 104320
3500 2500 500 300 01 100 350 18 124 68 98 01 03 32 01
00 200 50 200 200
C1 HMC 1 185 185 185 185 185 185 185 185 185 185 185 185 811
C2 HMGW 2 125 102 75 65 80 113 136 141 142 142 141 136 1842
C3 MWGT 3 81 76 69 56 53 53 55 61 68 77 82 83 1038
C4 LWGT 4 50 47 42 35 33 33 34 38 42 48 51 51 459
C5 OPWT 5 137 128 112 101 130 149 156 155 151 144 141 138 17

```

A1 ALFA 1 98 79 65 63 74 86 99 112 119 118 105 99 4121  
 A2 PAST 2 88 74 58 55 66 81 86 102 99 93 91 87 4488  
 A3 AOMA 3 84 77 62 55 66 81 94 109 115 118 105 95 1537  
 A4 SMGR 4 22 29 29 29 29 28 74 118 127 73 48 19 3054  
 A5 CORN 5 99 29 29 29 29 28 22 68 73 93 106 109 2013  
 A6 SUBT 6 102 29 29 29 29 28 22 58 95 106 120 111 235  
 A7 POTA 7 22 29 29 29 29 28 22 38 42 88 131 134 136  
 A8 ORCH 8 98 78 65 64 74 86 98 108 113 111 106 99 2023  
 A10 TOMA10 48 29 29 29 29 28 45 50 75 101 97 83 44  
 A11 SMTR11 48 29 29 29 29 28 37 62 77 82 78 61 137  
 A12 IDLE12 35 38 25 25 25 38 33 38 39 39 39 39 367  
 A13 BEAN13 25 29 29 29 29 28 22 67 111 89 75 28 12  
 -9999-9999-9999-9999-9999-9999-9999-9999-9999-9999

III. INPUT CONVERSION FACTORS  
 CARD 1 REPEATED FOR THE SIX SUBBASINS  
 1. 1..0036047,0036047,0036047,0036047,0036047,0036047,0036047,0036047,0036047,0036047,0036047,0036047,0036047,0036047,0036047,0036047  
 1. 1..0007259,0007259,0007259,0007259,0007259,0007259,0007259,0007259,0007259,0007259,0007259,0007259,0007259,0007259,0007259,0007259  
 1. 1..0006328,0006328,0006328,0006328,0006328,0006328,0006328,0006328,0006328,0006328,0006328,0006328,0006328,0006328,0006328,0006328  
 CARD 2  
 277,411377,51579,7

IV. CONSUMPTIVE USE FOR OPEN WATER  
 CARD 1  
 C5 OPWT 5 137 128 112 101 138 149 156 155 151 144 141 138

V. OUTPUT FORMATS  
 CARD 1  
 (1X,A4,2X,8F9,3)(1X,A4,2X,8F9,3)(1X,A4,2X,8F9,3)(1X,A4,2X,8F9,3)

VI. GAGED FLOW OF THE CORRELATION STREAMS  
 CARD 1  
 INPUT QCOR FOR YEAR ONE FOR THE THREE SUBBASINS(1950)  
 OAKL1950 51 44 39 36 33 37 136 468 776 236 83 65  
 OAKL1950 51 44 39 36 33 37 136 468 776 236 83 65  
 OAKL1950 51 44 39 36 33 37 136 468 776 236 83 65  
 THIS SET OF CARDS FOR 1950 IS FOLLOWED BY SIMILAR INPUT FOR THE YEARS 1951-69  
 VII. THE VAR(I,L) AND RVAR(I,L) DATA ARE READ FROM THE DATA TAPE DEVELOPED  
 USING THE DATA PROGRAM

## SAMPLE OUTPUT

L = 1950 K = 1

L = 1950 K = 1

ITEM	FRANCIS	A 2,3	A4567
TEMP	40,952	43,598	47,500
PRCP	1014.	4452.	6555.
SNOW	0.	0.	0.
QGIN	799.	8848.	13498.
QUNG	3640.	5368.	440.
QIMP	0.	0.	0.
QRTN	0.	0.	10.
QBSSE	396.	1221.	969.
QWEL	0.	0.	499.
QPRC	184.	0.	0.
QGW1	0.	594.	1831.
QIRR	0.	0.	0.
QMW1	0.	0.	99.
QEXP	0.	0.	1999.
QSRT	0.	0.	0.
ETPH	79.	238.	939.
ETCR	274.	1723.	2736.
SLMS	1664.	8238.	6978.
QTOT	5642.	15431.	15879.
QGW0	594.	1832.	2059.
QSOT	5048.	13599.	13820.
QGOT	4999.	13599.	13894.

## RESERVOIR

SUB BSN,	RGIN	RPPT	REVP	RDIV	RSPL	RRLS	RSTR	AJST
A 2,3	15949.	588.	369.	0.	0.	13600.	121369.	0.

L = 1950 K = 2

L = 1950 K = 2

ITEM	FRANCIS	A 2,3	A4567
TEMP	37,758	40,108	42,898
PRCP	591.	3267.	3105.
SNOW	233.	0.	0.
QGIN	1099.	8977.	15397.
QUNG	3021.	4755.	278.
QIMP	0.	0.	0.
QRTN	0.	0.	0.
QBSSE	205.	1135.	930.
QWEL	0.	0.	399.
QPRC	180.	0.	698.
QGW1	0.	307.	1702.
QIRR	0.	0.	0.
QMW1	0.	0.	0.
QEXP	0.	0.	399.
QSRT	0.	0.	0.
ETPH	51.	148.	560.
ETCR	172.	1090.	1487.
SLMS	1664.	10415.	7898.
QTOT	4686.	16301.	18707.
QGW0	307.	1702.	1978.
QSOT	4378.	14599.	16729.
QGOT	4399.	14598.	16793.

## RESERVOIR

SUB BSN,	RGIN	RPPT	REVP	RDIV	RSPL	RRLS	RSTR	AJST
A 2,3	15270.	439.	243.	0.	0.	14600.	122236.	0.





## APPENDIX D

### COMBINED UTAH LAKE OPERATION MODEL

The combined model is composed of the Utah Lake operation model developed by the Central Utah Project Office of the Bureau of Reclamation and the previously described river basin management model. Slight alteration of both of the programs was necessary to combine the models but the basic logic of the programs was not affected. The combined program is tied more to operation on a water year than any of the previously described models.

The use of the data program was eliminated in the combined model by directly inputting all data to the combined model. The input of VAR and RVAR data was altered so that all NYR years of data for each station could be input as a group as outlined in the input data layout. This is the same procedure used to input VAR data to the parameter calibration model.

A set of indications was used to replace the use of sense switches with "If" statements and provide additional logic tests. These indicators are outlined in the data input.

The management portion of the program simulates the Provo River flow, ungaged streamflow and ground-

water flow to Utah Lake. Additionally, this portion of the program tabulates the inflow to the lake from gaged surface sources. This becomes input to the Utah Lake operation portion of the combined model.

The original Utah Lake model was adapted to the combined model by redefining the basic variable, C(J,L,K). This allows certain variables to be transferred from the management portion of the program. The basic variables are listed in Table D-1. Calculation of precipitation on the lake and a total dissolved solids balance, as discussed in the text, were added to the Utah Lake operation portion of the study.

The output from the combined program is composed of two distinct portions. The management portion of the program outputs results of simulation for the NYR years followed by the output of the Utah Lake operation for the same time period. The output for the management portion of the combined program is the same as the output for the river basin management model. The output of the Utah Lake operation portion of the model is based on a water year and consists of monthly values for the C(J,L,K)'s.

# INPUT DATA LAYOUT

## I. Basic Data

Card 1 same as I Card 2 Appendix C  
Card 2 same as I Card 3 Appendix C

## II. Gaged Flow of the Correlation Streams (in Thousands of Acre Feet)

Col	Identifier	
Card 1-8		Identification
1 9-14	QCOR(1,1,1)	Correlation stream-flow for Subbasin 1 month 1 year 1
15-20	QCOR(1,1,2)	Correlation stream-flow for Subbasin 1 month 2 year 1
.	.	.
.	.	.
75-80	QCOR(1,1,12)	Correlation stream-flow for Subbasin 1 month 12 year 1

Format (8X,-3P12F6.1)

This card is repeated for year 2, 3, ..., NYR. This completes the correlation stream input data for Subbasin 1. This set is followed by a similar set of data for Subbasin 2, 3, ..., NSB.

## III. Indicators

Card 1 4	INAF	= 1 output monthly hydrology of the Provo River in inches = 2 output monthly hydrology of the Provo River in acre feet = 3 output only reservoir operation
8	NOUT	= 0 program outputs Provo River simulation = 1 program skips all output of the Provo River simulation (overrides INAF)
9-12	IPR	Subbasin number of the most downstream subbasin in the Provo River system
13-16	IUL	The subbasin number of the subbasin containing Utah Lake (IUL = IPR+1) or = 0 program operates as river basin management model with no lake operation

Format (4I4)

## IV. River Basin Data

Card 1 same as I	Card 4 Appendix C
Card 2 same as I	Card 5 Appendix C
Card 3 same as I	Card 6 Appendix C
Card 4 same as I	Card 7 Appendix C
Card 5 same as I	Card 8 Appendix C
Card 7 same as II	Card 1 Appendix C
Card 8 same as II	Card 2 Appendix C
Card 9 same as II	Card 3 Appendix C
Card 10 same as II	Card 4 Appendix C
Card 11 same as II	Card 5 Appendix C
Card 12 same as II	Card 6 Appendix C
Card 13 same as II	Card 7 Appendix C
Card 14 same as III	Card 1 Appendix C
Card 15 same as III	Card 2 Appendix C
Card 16 same as IV	Card 1 Appendix C
Card 17 same as V	Card 1 Appendix C

## V. Input Variable Data Indications

Card 1 same as II Card 1 Appendix B

With Only Four Formats

Card 2 same as II	Card 2 Appendix B
Card 3 same as III	Card 1 Appendix B
Card 4 same as IV	Card 1 Appendix B

## VI. Input VAR and RVAR Data

The VAR and RVAR data described in Table C-1 are input at this point. These variables are read in as DVAR and DRVAR in the program and then the stations for each variable are summed to form VAR and RVAR, respectively.

Each card must contain twelve monthly values and all stations of a specific variable must be in the same units and punched in the same format within a subbasin (refer to VI Card 1 Appendix B for use of input formats for the variables).

The following ending of the cards values, each containing twelve monthly values, is to be used:

Subbasin 1  
VAR(1) Station 1 Year 1, 2, 3, ..., NYR  
Station 2 Year 1, 2, 3, ..., NYR  
.  
.  
.  
Station NST(1,1) Year 1, 2, 3, ..., NYR  
VAR(2) Station 1 Year 1, 2, 3, ..., NYR  
Station 2 Year 1, 2, 3, ..., NYR  
.  
.  
.  
Station NST(1,2) Year 1, 2, 3, ..., NYR  
VAR(NVR) Station 1 Year 1, 2, 3, ..., NYR  
Station 2 Year 1, 2, 3, ..., NYR  
.  
.  
.  
Station NST(1,NVR) Year 1, 2, 3, ..., NYR  
If IRS(1) = 0, SKIP RVAR(L) input

RVAR(1)	Station 1	Year 1,2,3,...,NYR
	Station 2	Year 1,2,3,...,NYR
	.	
	.	
	.	
	StationNRST(1,1)	Year 1,2,3,...,NYR
RVAR(2)	Station 1	Year 1,2,3,...,NYR
	Station 2	Year 1,2,3,...,NYR
	.	
	.	
	.	
.	StationNRST(1,2)	Year 1,2,3,...,NYR
.		
RVAR(NRVR)	Station 1	Year 1,2,3,...,NYR
	Station 2	Year 1,2,3,...,NYR
	.	
	.	
	StationNRST(1,NRVR)	Year 1,2,3,...,NYR

This arrangement of cards is repeated for sub-basin 2, 3, ..., NSB. When any NST(I, L) or NRST(I, L) is equal to zero no cards are input for that VAR(L) or RVAR(L), respectively, of Subbasin I.

#### VII. Input Data for Utah Lake Operation

	<u>Col</u>	<u>Identifier</u>	
Card 1	1-12	TITLE	Title card which will appear at the top of each page put in the first 72 columns
			Format (12A6)
Card 2	1-8	CTDS	Conversion of ppm to a desired unit
	9-13	GWSC	Groundwater salt content, ppm
	14-21	SDEAD	Dead storage of Utah Lake, acre feet
	22-26	NUMENT	The number of values to be in the area-capacity tables of Utah Lake expressed as an integer
	27-31	NUGNT	The number of values to be in the area-capacity tables of Goshen Bay expressed as an integer
	32-36	KPPT	Number of precipitation stations to be input for calculation of precipitation on Utah Lake
	37-41	DLS	A dummy lake storage used in calculating total dissolved solids when the lake content is zero

Format (F8.5, F5.0, F8.2, 3I5, F5.1)

Card 3	1-10	CPPT(1)	The weighting factor to be applied to lake precipitation station 1
	11-20	CPPT(2)	The weighting factor to be applied to lake precipitation station 2
		.	.
		.	.
		.	.
		CPPT(KPPT)	The weighting factor to be applied to lake precipitation station KPPT

Format (8F10.0)

Card 4 The lake precipitation, BPPT(I, J) data is input at this point. NYR years of data are input for station 1 with one year of monthly data in inches of water per card. The cards are arranged in ascending yearly order. A similar set is input for station 2, 3, ..., KPPT. This is the same technique used to input the VAR & RVAR data to this program.

Format (8X, 12F6.2)

Card 5	1-6	C(14, 1, 1)	Initial value of C(14, L, K), thousands of acre feet
	7-12	C(13, 1, 1)	Initial value of C(13, L, K), thousands of acre feet
	13-18	C(21, 1, 1)	Initial value of C(21, L, K), thousands of acre feet
	19-24	C(20, 1, 1)	Initial value of C(20, L, K), thousands of acre feet
	25-34	C(29, 1, 1)	Initial value of C(29, L, K), in tons

Format (4F6.1, F10.0)

Card 6	AREAS(J)	Values of area of diked lake from area-capacity curve punched 10 numbers per card for NUMENT values as shown on Card 2
--------	----------	--

Format (10F8.1)

Card 7	CAP(J)	Values of capacity of diked lake from area-capacity curve as explained in Card 6
--------	--------	--

Format (10F8.1)

Card 8	AREASG(J)	Values of area from area-capacity curve for Goshen Bay as explained in Card 6
--------	-----------	---

Card 9	Format (10F8. 1)		15-20	DMND(2, 3)	The demand placed on Utah Lake from the Mosida area month 2
	CAPG(J)	Values of capacity from area-capacity curve for Goshen Bay as explained in Card 6		.	.
				.	.
Card 10	Format (10F8. 1)		75-80	DMND(2, 13)	The demand placed on Utah Lake from the Mosida area month 12
	SPILLS(J)	17 values of spill rates from Utah Lake into Jordan River based on the elevation of the lake			
Card 11	Format (10F8. 1)		Card 9-14 16	QRTN(2)	Return inflow to Goshen Bay from the Mosida area month 1
	CH(J)	Values of differential change in water surface elevation between Goshen Bay and Utah Lake to be used in determining the value of flow rate from the lake to the bay	15-20	QRTN(3)	Return inflow to Goshen Bay from the Mosida area month 2
				.	.
Card 12	Format (12F6. 2)		75-80	QRTN(13)	Return inflow to Goshen Bay from the Mosida area month 12
	ELEV(J)	Values of elevation of water surface in Utah Lake to be used with Card 11	Card 17	WEVP(I, J)	The rate of evaporation from Goshen Bay expressed in feet, with 12 months of record on each card, 1 card for each year of the study
Card 13	Format (12F6. 2)		Card 18	HISA(I, J)	Historical average water surface area, with 12 months of record on each card, 1 card for each year of the study, in thousands of acres
	QQQ(M, N)	A table of discharge values from Utah Lake into Goshen Bay as related to the elevation of the lake and the differential head between the two bodies of water			
Format (11I5)					
The relationship between CH(J), ELEV(J), and QQQ(M, N) is given in Table D-1.					
Card 9-14 14	DMND(1, 2)	The demand placed on Utah Lake from Jordan River month 1	Card 19	C(16, I, J)	Values to reduce the lake inflow by withholding Goshen Bay inflow, with 12 months of record on each card, 1 card for each year of the study, in thousands of acre feet
	15-20	DMND(1, 3)			
	.	.			
75-80	DMND(1, 13)	The demand placed on Utah Lake from Jordan River month 12			
Format (8X, 12F6. 1)					
Card 9-14 15	DMND(2, 2)	The demand placed on Utah Lake from the Mosida area month 1			

# Elevation of Utah Lake

ELEV (N), N = 1, 11

Head difference between diked lake and Goshen Bay. CH(M), M = 1, 10	QQQ (1, 1)	QQQ (1, 2)	. . . . .	QQQ (1, 11)
	QQQ (2, 1)	QQQ (2, 2)	. . . . .	QQQ (2, 11)
	.	.		.
	.	.		.
	.	.		.
	.	.		.
	.	.		.
	.	.		.
	.	.		.
	QQQ (10, 1)	QQQ (10, 2)	. . . . .	QQQ (10, 11)

QQQ (M,N) is a spillrate into Goshen Bay which depends on the elevation of the diked lake and head difference. The CH (M) and ELEV (N) are used to determine the position in the QQQ (M,N) Table. The spillrate in CFS into Goshen Bay is found by interpolation.

Table D 1. Determination of spillrate into Goshen Bay.

# COMBINED UTAH LAKE OPERATION MODEL PROGRAM LISTING

```

C RIVER BASIN OPERATION MODEL
COMMON/JOBTIT/ TITLE(12),IPAGE
COMMON/BLK1/AREA(7,4)
COMMON AJST(7) ,GCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
1ACOR(7) , CAF(7),CCR(12),CONV(7,13),CPH(12),CMS(12),DLH(12),
2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SOSIR(7,12),SIM(7,18),
4SYIC(7,6),TACR(7),TAPH(7),MCR(7,12),NPH(7,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSRV(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
COMMON ACR, AJSO,APH,CAJS,OIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
3IPR,IUL, LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
1,NVR,INAF,
7VAR(41,12,7,13)
DIMENSION BSNM(4),NST(8,14),NRST(8,2),IFMT(8,14)
C INPUT BASIC DATA
1 READ(5,100,END=27) (BSNM(II),II=1,4),NSB,NVR,NPR,NSM,NRVR,NRPR,
1NRSM,NIND,NARA,NSIC,LYRO,NYR,IN1,IN2,IOUT,NITX,AJSO,ADMS,CAJS,
2ITOP,DAJS
100 FORMAT(4A4,10I3/I5,5I3,3F5.2,15,F5.0)
DO 2 I=1,NSB
DO 2 J=1,NYR
2 READ(IN1,101) (GCOR(J,I,K),K=1,12)
101 FORMAT(8X,-3P12F6.1)
C INAF IS THE CONTROL ON TYPE OF OUTPUT FOR THE PROVO RIVER
C SIMULATION
C NOUT IS THE CONTROL TO OUTPUT THE PROVO RIVER SIMULATION. NOUT=0
C WILL OUTPUT RESULTS. NOUT=1 WILL RESULT IN NO OUTPUT OF THE
C PROVO RIVER SIMULATION
C IPR IS THE NUMBER OF THE LOWEST SUBBASIN IN THE PROVO RIVER SYSTEM
C IUL IS THE NUMBER OF THE SUBBASIN CONTAINING UTAH LAKE
C READ(IN1,99) INAF,NOUT,IPR,IUL
99 FORMAT(4I4)
CALL BSOTA
READ(IN1,102) (AFMT1(L),L=1,4),(AFMT2(L),L=1,4),(AFMT3(L),L=1,4),
1(AFMT4(L),L=1,4)
102 FORMAT(5(4A4))
C INPUT FORMAT INDICATOR FOR INPUT DATA
C DO 3 I=1,NSB
3 READ(IN1,104) (IFMT(I,L),L=1,NVR)
104 FORMAT(20I4)
C INPUT STATION NUMBER
C DO 4 I=1,NSB
4 READ(IN1,104) (NST(I,L),L=1,NVR),(NRST(I,L),L=1,NRVR)
C INPUT STATION HEIGHT FOR TEMPERATURE AND PRECIPITATION
C DO 5 I=1,NSB
DO 5 L=1,2
NSTN=NST(I,L)
5 READ(IN1,103) (CWT(I,L,M),M=1,NSTN)
103 FORMAT(16F5.2)
C DO 19 J=1,NYR
DO 19 K=1,12
DO 19 I=1,NSB
DO 18 LL=1,NRVR
18 RVAR(J,K,I,LL)=0.0
DO 19 L=1,NVR
19 VAR(J,K,I,L)=0.0
DO 25 I=1,NSB
DO 20 L=1,NVR
NSTN=NST(I,L)
IF(NSTN,LE,0) GO TO 20
DO 420 M=1,NSTN
DO 320 J=1,NYR
LFMT=IFMT(I,L)
GO TO (6,7,8,9),LFMT

```

```

6 READ(IN1,AFMT1) (DVAR(K),K=1,12)
GO TO 11
7 READ(IN1,AFMT2) (DVAR(K),K=1,12)
GO TO 11
8 READ(IN1,AFMT3) (DVAR(K),K=1,12)
GO TO 11
9 READ(IN1,AFMT4) (DVAR(K),K=1,12)
11 DO 220 K=1,12
IF(L,LE,2) GO TO 12
VAR(J,K,I,L)=VAR(J,K,I,L)+DVAR(K)*CONV(I,L)
GO TO 220
12 VAR(J,K,I,L)=VAR(J,K,I,L)+DVAR(K)*CWT(I,L,M)
220 CONTINUE
320 CONTINUE
420 CONTINUE
20 CONTINUE
IF(IND(I,5),EQ,0) GO TO 25
DO 225 LL=1,NRVR
NSTN=NRST(I,LL)
IF(NSTN,LE,0) GO TO 225
DO 325 MM=1,NSTN
DO 425 JJ=1,NYR
READ(IN1,110) (DRVAR(K),K=1,12)
110 FORMAT(8X,-3P12F6.1)
DO 525 K=1,12
RVAR(JJ,K,I,LL)=RVAR(JJ,K,I,LL)+DRVAR(K)
525 CONTINUE
425 CONTINUE
325 CONTINUE
225 CONTINUE
25 CONTINUE
C REPEAT SIMULATION FOR EACH YEAR
DO 26 J=1,NYR
LYR=LYRO+J-1
C REPEAT SIMULATION FOR EACH MONTH
DO 17 K=1,12
MNTH=0+K
IF(K,GT,3) MNTH=K-3
C SIMULATION OPERATION
CALL RBOS (J,K)
IF(NOUT,EQ,1) GO TO 17
GO TO (30,31,16),INAF
C IF INAF = 1, OUTPUT MONTHLY HYDROLOGY IN INCHES
C 30 CALL OTPTS(FMT1,FMT2,K,J)
GO TO 16
C IF INAF = 2, OUTPUT MONTHLY HYDROLOGY IN ACRE-FEET
C 31 DO 15 I=1,NSB
DO 13 L=2,NVR
13 VAR(J,K,I,L)=CAF(I)+VAR(J,K,I,L)
DO 14 L=1,NSM
14 SIM(I,L)=CAF(I)+SIM(I,L)
VAR3(I)=CAF(I)+VAR3(I)
15 CONTINUE
CALL OTPTS(FMT3,FMT4,K,J)
DO 52 I=1,NSB
DO 50 L=2,NVR
50 VAR(J,K,I,L)=VAR(J,K,I,L)/CAF(I)
DO 51 L=1,NSM
51 SIM(I,L)=SIM(I,L)/CAF(I)
VAR3(I)=VAR3(I)/CAF(I)
52 CONTINUE
C OUTPUT MONTHLY RESERVOIR OPERATION IN ACRE-FEET
C 16 CALL OTPTR (K)
17 CONTINUE
26 CONTINUE
IF(IUL,GT,0) CALL LAKE
GO TO 1
27 STOP
END

```

```

C      SUBROUTINE FOR BASIC DATA
      SUBROUTINE BSDTA
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7) , QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
      1ACOR(7) , CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
      2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
      3RPR(7,18),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
      4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
      5FMT3(4),FMT4(4),GSRV(7),GGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
      6,CMT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)

C      COMMON ACR, AJSD,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
      1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSH,NVR,
      2 SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
      3IPR,IUL, LYRO,CAP(1818),NUMENT,CAPG(1788),NUGNT,C(38,13,45)
      1,NVR,INAF,
      7VAR(41,12,7,13)
C      READ OUTPUT ROW TITLES
      READ(IN1,188) (OTL(L),L=1,NSM)
      READ(IN1,188) (ROTL(L),L=1,NRSM)
      READ(IN1,188) (OTLV(L),L=1,4)
100  FORMAT(20A4)

C      READ AND CHECK FRACTION DAY-LIGHT HOURS
      READ(IN1,181) (DLH(K),K=1,12),MSIR,MEIR
101  FORMAT(12F5,3,2I3)

C      INPUT UNGAGED WATERSHED TEMPERATURE ADJUSTMENT
      READ(IN1,120) (TMP1(I),I=1,NSB)
120  FORMAT(10X,10F5,2)

C      INPUT MODEL INDICATORS AND PARAMETERS FOR EACH SUB-BASIN
      DO 12 I=1,NSB
      READ(IN1,182) (SBNM(I,L),L=1,2), (IND(I,L),L=1,NIND), (AREA(I,L),L=1
      1,NARA)
102  FORMAT(2A4,2X,5I5,4F10,0)
      READ(IN1,183) (PR(I,L),L=1,NPR)
103  FORMAT(16F5,2)
      IF(IND(I,5).EQ.0) GO TO 41
      DO 48 L=1,NRPR
      40  RPR(I,L)=0.
      GO TO 42
      41  READ(IN1,184) (RPR(I,L),L=1,NRPR)
104  FORMAT(4F8,0,6F8,5)

C      INPUT INITIAL CONDITIONS
      42  READ(IN1,185) (SYIC(I,L),L=1,NSIC)
105  FORMAT(5F5,2,F10,0)

C      COMPUTE WEIGHTED PHREATOPHYTE AND CROP CONSUMATIVE USE COEFFICIENT
      DO 3 K=1,12
      3  WPH(I,K)=0.
      TAPH(I)=0.
      N=IND(I,2)
      DO 5 L=1,N
      READ(IN1,186) (CPH(K),K=1,12),APH
106  FORMAT(10X,12F5,2,F10,0)
      DO 4 K=1,12
      4  WPH(I,K)=WPH(I,K)+CPH(K)*APH
      5  TAPH(I)=TAPH(I)+APH
      DO 6 K=1,12
      6  WPH(I,K)=WPH(I,K)/TAPH(I)
      TACR(I)=0.
      DO 7 K=1,12
      7  WCR(I,K)=0.
      IF(IND(I,1).EQ.0) GO TO 11
      N=IND(I,1)
      DO 9 L=1,N
      READ(IN1,186) (CCR(K),K=1,12),ACR
      DO 8 K=1,12
      8  WCR(I,K)=WCR(I,K)+CCR(K)*ACR
      9  TACR(I)=TACR(I)+ACR
      DO 10 K=1,12
      SDSIR(I,K)=0.

```

```

10  WCR(I,K)=WCR(I,K)/TACR(I)
11  READ(IN1,187) (QDSIR(I,K),K=1,12)
107  FORMAT(12F5,0)
      IF(IND(I,5).EQ.0) GO TO 12
      READ(IN1,188) (SDSIR(I,K),K=1,12)
108  FORMAT(12F6,0)
12  CONTINUE

```

```

C      READ AND CHECK CONVERSION FACTORS
      DO 28 I=1,NSB
      READ(IN1,189) (CONV(I,L),L=1,NVR)
109  FORMAT(10F8,5)
      28  CONTINUE
      READ(IN1,188) (CAF(I),I=1,NSB)

C      READ CONSUMPTIVE USE COEFFICIENT FO OPEN WATER
      READ(IN1,186) (CWS(K),K=1,12)

```

```

C      READ OUTPUT FORMAT
      READ(IN1,110) (FMT1(L),L=1,4), (FMT2(L),L=1,4), (FMT3(L),L=1,4),
      1(FMT4(L),L=1,4)
110  FORMAT(16A4)
      RETURN
      END

```

```

C      SUBROUTINE FOR OPERATION STUDY
      SUBROUTINE RBOS (J,K)
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7) , QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
      1ACOR(7) , CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
      2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
      3RPR(7,18),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
      4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
      5FMT3(4),FMT4(4),GSRV(7),GGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
      6,CMT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON ACR, AJSD,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
      1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSH,NVR,
      2 SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
      3IPR,IUL, LYRO,CAP(1818),NUMENT,CAPG(1788),NUGNT,C(38,13,45)
      1,NVR,INAF,
      7VAR(41,12,7,13)
      DIMENSION TRCO(7),TBGO(7)
      REAL MS1,MS
      L1=1
      L2=2
      L3=3
      L4=4
      L5=5
      L6=6
      L7=7
      L8=8
      L9=9
      L10=10
      L11=11
      L12=12
      DO 47 I=1,NSB
      AJST(I)=0.
      47  PRLS(I)=RVAR(J,K,I,1)
      TSAVA(1)=0.
      TSAVA(2)=0.
      I=0
      IMX=0
      4  I=I+1
      44  IF(I.GT.IMX) GO TO 60
      GO TO 61
      60  ISOS=1
      JSOS=1
      IMX=I
      61  IF(I.LE.1) GO TO 49
      VAR3(I)=VAR(J,K,I,L3)+GSRV(I-1)*12./AREA(I,3)
      VAR4(I)=VAR(J,K,I,L4)+GGRY(I-1)*12./AREA(I,3)
      GO TO 52
      49  VAR3(I)=VAR(J,K,I,L3)
      VAR4(I)=VAR(J,K,I,L4)

```



```

C      SNOW STORAGE AND SNOWMELT
52 CALL SNMHT (I,RPMT,RPMT1,J,K)
C
C      PHREATOPHYTE EVAPOTRANSPIRATION
BCF=VAR(J,K,I,L1)*DLH(K)
BCK=.0173*VAR(J,K,I,L1)-.314
IF(BCK.LT..3) BCK=.3
SIM(I,13)=PR(I,9)*WPH(I,K)+BCF*BCK*TAPH(I)/AREA(I,3)
C
C      CROP POTENTIAL EVAPOTRANSPIRATION AND WATER SUPPLIES
IF(IND(I,1).EQ.0) GO TO 10
ETP=PR(I,9)*MCR(I,K)+BCF*BCK
IF(IND(I,3).EQ.0) GO TO 9
IF(MNTH.GE.MSIR.AND.MNTH.LE.MEIR) GO TO 8
VAR(J,K,I,L7)=0.0
VAR(J,K,I,L9)=0.0
GO TO 9
8 VAR(J,K,I,L7)=ETP/PR(I,10)=(RPMT+VAR(J,K,I,L5)+VAR(J,K,I,L9)
1=VAR(J,K,I,L11))
IF(VAR(J,K,I,L7).LT.0.) VAR(J,K,I,L7)=0.0
9 SIM(I,9)=VAR(J,K,I,L5)+VAR(J,K,I,L7)+VAR(J,K,I,L9)=VAR(J,K,I,L11)
IF(SIM(I,9).GE.0.) GO TO 70
VAR(J,K,I,L11)=VAR(J,K,I,L11)+SIM(I,9)
SIM(I,9)=0.
70 DAG=SIM(I,9)*PR(I,10)+RPMT
GO TO 11
10 ETP=0.
SIM(I,9)=0.
DAG=0.
11 SIM(I,10)=VAR(J,K,I,L8)+VAR(J,K,I,L8)+VAR(J,K,I,L10)
1=VAR(J,K,I,L12)
C
C      RETURN FLOW
IF(IND(I,1).EQ.0) GO TO 12
SIM(I,4)=(1.-PR(I,10))*SIM(I,9)+(1.-PR(I,11))*SIM(I,10)
GO TO 13
12 SIM(I,4)=(1.-PR(I,11))*SIM(I,10)
C
C      UNGAGED SURFACE INFLOW
13 SIM(I,2)=PR(I,5)*AREA(I,2)/AREA(I,4)+QCOR(J,I,K)*12./AREA(I,3)+
1PR(I,12)+RPMT1*AREA(I,2)/AREA(I,3)+PR(I,13)*(AREA(I,1)+AREA(I,2))/
2AREA(I,3)
C
C      EVAPOTRANSPIRATION, SOIL MOISTURE, AND PERCOLATION
IF(IND(I,1).EQ.0) GO TO 19
MS1=SYIC(I,2)
NITR=1
14 SIM(I,14)=ETP*MS1/PR(I,4)
IF(SIM(I,14).LT.0.) SIM(I,14)=0.
IF(SIM(I,14).GT.ETP) SIM(I,14)=ETP
MS=SYIC(I,2)+DAG-SIM(I,14)
IF(MS.GT.PR(I,3)) GO TO 15
SIM(I,7)=0.
GO TO 16
15 SIM(I,7)=MS-PR(I,3)
MS=PR(I,3)
16 DHS=ABS(MS-MS1)
MS1=(MS+SYIC(I,2))/2.
IF(DHS.GT.ADMS.AND.NITR.LT.NITX) GO TO 17
GO TO 18
17 NITR=NITR+1
GO TO 14
18 SIM(I,15)=MS
GO TO 20
19 SIM(I,7)=0.
SIM(I,14)=0.
SIM(I,15)=0.
C
C      GROUNDWATER RECHARGE AND OUTFLOW
20 DIN=PR(I,15)+RPMT*(AREA(I,1)+AREA(I,2))/AREA(I,3)
SK=PR(I,6)
DIC=SYIC(I,4)
CALL ROUT
TRCO(I)=DOUT

```

```

DIN=VAR4(I)+DOUT+SIM(I,7)-VAR(J,K,I,L9)-VAR(J,K,I,L10)
SK=PR(I,7)
DIC=SYIC(I,5)
CALL ROUT
TBGO(I)=DOUT
SIM(I,5)=PR(I,14)+DOUT
SIM(I,17)=DOUT-SIM(I,5)
C
C      SURFACE OUTFLOW
21 SIM(I,18)=VAR3(I)+SIM(I,2)+SIM(I,4)+SIM(I,5)-VAR(J,K,I,L7)
1=VAR(J,K,I,L8)-SIM(I,13)+RPMT*TAPH(I)/AREA(I,3)
C
C      RESERVOIR OPERATION
IF(IND(I,5).EQ.0) GO TO 22
CALL RSOP (K,I,JSOS,J)
SIM(I,18)=(RSIM(I,5)+RSIM(I,6))*12./AREA(I,3)
GO TO 23
22 SAJS=0.
SAVA(I,1)=0.
SAVA(I,2)=0.
23 TSAVA(1)=TSAVA(1)+SAVA(I,1)
TSAVA(2)=TSAVA(2)+SAVA(I,2)
CALL RRLS(I,K,JSOS)
IF(JSOS.EQ.0.AND.ISOS.EQ.1) GO TO 44
40 QGRY(I)=SIM(I,18)+AREA(I,3)/12.
IF(QGRY(I).LT.0.) QGRY(I)=0.
QGRY(I)=SIM(I,17)+AREA(I,3)/12.
IF(QGRY(I).LT.0.) QGRY(I)=0.
IF(I.NE.IUL) GO TO 80
IK=K+1
C(I,IK,J)=SIM(IPR,18)+CAF(IPR)/1000.
C(2,IK,J)=VAR(J,K,I,L3)*CAF(I)/1000.
C(3,IK,J)=SIM(I,2)+CAF(I)/1000.
C(4,IK,J)=SIM(I,17)+CAF(I)/1000.
80 IF(I.LT.NSB) GO TO 4
C
C      COMPLETE SIM ARRAY
DO 39 I=1,NSB
SIM(I,3)=VAR(J,K,I,L5)+VAR(J,K,I,L6)
SIM(I,6)=VAR(J,K,I,L9)+VAR(J,K,I,L10)
SIM(I,8)=VAR4(I)
SIM(I,11)=VAR(J,K,I,L11)+VAR(J,K,I,L12)
IF(IND(I,5).GE.1) SIM(I,11)=VAR(J,K,I,L11)+VAR(J,K,I,L12)
1+RSIM(I,4)*12./AREA(I,3)
SIM(I,12)=QDSIR(I,K)*1.98*30.*12./AREA(I,3)-SIM(I,18)
IF(SIM(I,12).LT.0.) SIM(I,12)=0.
SIM(I,16)=SIM(I,17)+SIM(I,18)
C
C      RESET INITIAL VALUES
SYIC(I,1)=SIM(I,1)
SYIC(I,2)=SIM(I,15)
SYIC(I,4)=TRCO(I)
SYIC(I,5)=TBGO(I)
IF(IND(I,5).EQ.1) SYIC(I,6)=RSIM(I,7)
39 CONTINUE
END
C
SUBROUTINE FOR SNOW MELT
SUBROUTINE SNMHT (I,RPMT,RPMT1,J,K)
COMMON/BLK1/AREA(7,4)
COMMON AJST(7), QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
1ACOR(7), CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
3RPR(7,18),RVAR(41,12,7,2),8BNM(7,2),SDSIR(7,12),SIM(7,18),
4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
5PMT3(4),PMT4(4),QGRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
COMMON ACR, AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
1MEIR,MNTH,MSIR,NARA,WIND,NITX,NPR,NRPR,NRSH,NRVR,NSIC,NSB,NSM,NVR,
2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
3IPR,IUL, LYRO,CAF(1810),NUMENT,CAPG(1780),NUGNT,C(38,13,45)
1,NVR,INAF,
7VAR(41,12,7,13)
L1=1

```

```

      L2=2
52 IF (VAR(J,K,I,L1).GT.PR(I,1).AND.VAR(J,K,I,L1).GT.PR(I,2)) GO TO 6
   IF (VAR(J,K,I,L1).LE.PR(I,1).AND.VAR(J,K,I,L1).GT.PR(I,2)) GO TO 5
   SIM(I,1)=SYIC(I,1)+VAR(J,K,I,L2)
   SNMT=0.
   RPMT=0.
   GO TO 7
5 SIM(I,1)=SYIC(I,1)+VAR(J,K,I,L2)
   SNMT=SIM(I,1)*(1.-EXP(-PR(I,8)*(VAR(J,K,I,L1)-PR(I,2))))
   IF (SNMT.GT.SIM(I,1)) SNMT=SIM(I,1)
   SIM(I,1)=SIM(I,1)-SNMT
   RPMT=SNMT
   GO TO 7
6 SNMT=SYIC(I,1)*(1.-EXP(-PR(I,8)*(VAR(J,K,I,L1)-PR(I,2))))
   IF (SNMT.GT.SYIC(I,1)) SNMT=SYIC(I,1)
   SIM(I,1)=SYIC(I,1)-SNMT
   RPMT=VAR(J,K,I,L2)+SNMT
7 TUNG=VAR(J,K,I,L1)-TMP1(I)
   IF (TUNG.GT.PR(I,1).AND.TUNG.GT.PR(I,2)) GO TO 41
   IF (TUNG.LE.PR(I,1).AND.TUNG.GT.PR(I,2)) GO TO 90
   SNW1=SYIC(I,3)+VAR(J,K,I,L2)
   RPMT1=0.
   GO TO 42
90 SNW1=SYIC(I,3)+VAR(J,K,I,L2)
   SNMT1=SNW1*(1.-EXP(-PR(I,8)*(TUNG-PR(I,2))))
   IF (SNMT1.GT.SNW1) SNMT1=SNW1
   SNW1=SNW1-SNMT1
   RPMT1=SNMT1
   GO TO 42
41 SNMT1=SYIC(I,3)*(1.-EXP(-PR(I,8)*(TUNG-PR(I,2))))
   IF (SNMT1.GT.SYIC(I,3)) SNMT1=SYIC(I,3)
   SNW1=SYIC(I,3)-SNMT1
   RPMT1=VAR(J,K,I,L2)+SNMT1
42 SYIC(I,3)=SNW1
   RETURN
C
C SUBROUTINE FOR RESERVOIR RELEASE ADJUSTMENTS
C SUBROUTINE RRLS(I,K,JSOS)
COMMON/BLK1/AREA(7,4)
COMMON AJST(7) ,QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
1ACOR(7) , CAF(7),CCR(12),CONV(7,13),CPH(12),CHS(12),DLH(12),
2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SBSIR(7,12),SIM(7,18),
4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSRV(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
COMMON ACR, AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LVR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),ORVAR(12),ADMS,
3IPR,IUL, LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
1,NYR,INAF,
7VAR(41,12,7,13)
C
C CHECK FOR DESIRABLE FLOW AND ADJUST RESERVOIR RELEASE
QS=SIM(I,18)*AREA(I,3)/(12.*30.*1.98)
IF (QS.LT.QDSIR(I,K)) GO TO 24
QAJ=0.
GO TO 25
24 QAJ=(QDSIR(I,K)-QS)+1.98*30.
25 TAJS=CAJS*(SAJS+QAJ)+DAJS
   IF (ISOS.LE.0) GO TO 38
   IF (TAJS.LE.AJSO) GO TO 42
   IF (TSAVA(1).LT.TAJS) GO TO 30
C
C SUFFICIENT WATER AVAILABLE IN RESERVOIRS
TAJS1=TAJS
TAJS2=0.
40 IF (IND(I,5).LE.0) GO TO 41
   AJST(I)=TAJS1-SAJ
   IF (RSIM(I,5).GT.0.) AJST(I)=TAJS1+RSIM(I,5)
   GO TO 44
41 AJST(I)=0.
44 SAJS=0.
45 IF (TAJS1.GT.SAVA(I,1)) GO TO 50
   GO TO 28
50 IF (I.LE.ITOP) GO TO 28
   TAJS1=TAJS1-SAVA(I,1)
   I=I-1
   GO TO 40
28 TAJS1=0.
   IF (I.LE.ITOP) GO TO 37
   IM1=I-1
   DO 29 II=ITOP,IM1
39 AJST(II)=0.
   GO TO 37
C
C STORAGE LESS THAN DESIRABLE IN SOME OR ALL RESERVOIRS
30 TAJS1=TSAVA(1)
   TAJS2=TAJS-TAJS1
   IF (TAJS2.LE.SAJ) GO TO 90
   TAJS=TAJS-SAJ
   TAJS2=TAJS2-SAJ
   SAJS=0.
   GO TO 91
90 SAJS=SAJS-TAJS2
   TAJS=TAJS1
   TAJS2=0.
91 IF (TSAVA(2).LT.TAJS2) GO TO 35
59 IF (IND(I,5).LE.0) GO TO 61
   AJST(I)=TAJS-SAJ
   IF (RSIM(I,5).GT.0.) AJST(I)=TAJS+RSIM(I,5)
   GO TO 65
61 AJST(I)=0.
65 SAJS=0.
60 IF (TAJS2.GT.SAVA(I,2)) GO TO 51
   GO TO 33
51 IF (I.LE.ITOP) GO TO 33
   TAJS2=TAJS2-SAVA(I,2)
   TAJS=TAJS-SAVA(I,1)-SAVA(I,2)
   I=I-1
   GO TO 59
33 TAJS2=0.
   IF (I.LE.ITOP) GO TO 37
   IM1=I-1
   AJCO=0.
   DO 34 II=ITOP,IM1
   IF (IND(II,5).LE.0) GO TO 80
   AJST(II)=SAVA(II,1)+AJCO
   IF (RSIM(II,5).GT.0.) AJST(II)=AJST(II)+RSIM(II,5)
   AJCO=AJST(II)
   GO TO 34
80 AJST(II)=0.
34 CONTINUE
   GO TO 37
C
C STORAGE LESS THAN MINIMUM IN SOME OR ALL RESERVOIRS
35 TAJS=TSAVA(1)+TSAVA(2)
70 IF (IND(I,5).LE.0) GO TO 71
   AJST(I)=TAJS
   IF (RSIM(I,5).GT.0.) AJST(I)=TAJS+RSIM(I,5)
   GO TO 72
71 AJST(I)=0.
72 IF (I.LE.ITOP) GO TO 37
   TAJS=TAJS-SAVA(I,1)-SAVA(I,2)
   I=I-1
   GO TO 70
37 II=ITOP
   TSAVA(1)=0.
   TSAVA(2)=0.
   JSOS=0
   GO TO 38
42 AJST(I)=0.
   TAJS=0.
38 RETURN
END

```

```

C SUBROUTINE FOR LINEAR RESERVOIR ROUTING
SUBROUTINE ROUT
COMMON/BLK1/AREA(7,4)
COMMON AJST(7), QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
1ACOR(7), CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
3RPR(7,18),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QGRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
6,CMT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
COMMON ACR, AJ80,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LVR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSH,NRVR,NSIC,NSB,NSH,NVR,
2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
3IPR,IUL, LYRO,CAP(1818),NUMENT,CAPG(1788),NUGNT,C(38,13,45)
1,NVR,INAF,
7VAR(41,12,7,13)
DOUT=DIN*(DIC-DIN)*EXP(-1./SK)
RETURN
END
C SUBROUTINE FOR RESERVOIR OPERATION
SUBROUTINE RSOP (K,I,JSOS,J)
COMMON/BLK1/AREA(7,4)
COMMON AJST(7), QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
1ACOR(7), CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
3RPR(7,18),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QGRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
6,CMT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
COMMON ACR, AJ80,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LVR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSH,NRVR,NSIC,NSB,NSH,NVR,
2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
3IPR,IUL, LYRO,CAP(1818),NUMENT,CAPG(1788),NUGNT,C(38,13,45)
1,NVR,INAF,
7VAR(41,12,7,13)
L2=8
NITR=1
RSIM(I,4)=RVAR(J,K,I,2)
C RESERVOIR INFLOW
RSIM(I,1)=SIM(I,18)*AREA(I,3)/12.
C RESERVOIR RELEASE
PRLS(I)=PRLS(I)+AJST(I)
RSIM(I,6)=PRLS(I)
C RESERVOIR EVAPORATION
REVP=CWS(K)*BCF*BCK
SIC=SYIC(I,6)
CALL AREB(SIC,AR1,I)
1 RSIM(I,2)=VAR(J,K,I,2)*AR1/12.
RSIM(I,3)=REVP*AR1/12.
C RESERVOIR STORAGE
RSIM(I,7)=SIC+RSIM(I,1)+RSIM(I,2)+RSIM(I,3)+RSIM(I,4)+RSIM(I,6)
C SPILL FLOW
IF (RSIM(I,7).LE.RPR(I,4)) GO TO 2
RSIM(I,5)=RSIM(I,7)-RPR(I,4)
RSIM(I,7)=RPR(I,4)
GO TO 6
2 RSIM(I,5)=8.
IF (RSIM(I,7).GE.RPR(I,1)) GO TO 6
RSRT=RPR(I,1)-RSIM(I,7)
IF (RSRT.GT.RVAR(J,K,I,2)) GO TO 3
RSIM(I,4)=RVAR(J,K,I,2)-RSRT
RSIM(I,7)=RPR(I,1)
GO TO 6
3 RSIM(I,4)=8.
RSRT=RSRT-RVAR(J,K,I,2)
IF (RSRT.GT.RSIM(I,6)) GO TO 4
RSIM(I,6)=RSIM(I,6)-RSRT
RSIM(I,7)=RPR(I,1)
GO TO 6

```

```

4 RSRT=RSRT-RSIM(I,6)
RSIM(I,6)=8.
IF (RSRT.GT.RSIM(I,3)) GO TO 5
RSIM(I,7)=RPR(I,1)-RSRT
GO TO 6
5 RSIM(I,7)=RPR(I,1)-RSIM(I,3)
C CHECK FOR AVAILABLE AND DESIRABLE STORAGES
6 SAVA(I,1)=RSIM(I,7)-SDSIR(I,K)
IF (SAVA(I,1).LT.0.) SAVA(I,1)=8.
SAVA(I,2)=RSIM(I,7)-RPR(I,1)-SAVA(I,1)
IF (SAVA(I,2).LT.0.) SAVA(I,2)=8.
IF (RSIM(I,7).LT.SDSIR(I,K)) GO TO 8
SAJS=8.
GO TO 9
8 SAJS=SDSIR(I,K)-RSIM(I,7)
9 IF (JSOS.EQ.0) ISOS=8
RETURN
END
C SUBROUTINE FOR RESERVOIR WATER SURFACE AREA
SUBROUTINE AREB(S,AR,I)
COMMON/BLK1/AREA(7,4)
COMMON AJST(7), QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
1ACOR(7), CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
3RPR(7,18),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QGRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
6,CMT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
COMMON ACR, AJ80,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LVR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSH,NRVR,NSIC,NSB,NSH,NVR,
2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
3IPR,IUL, LYRO,CAP(1818),NUMENT,CAPG(1788),NUGNT,C(38,13,45)
1,NVR,INAF,
7VAR(41,12,7,13)
IF (S.LT.RPR(I,2)) GO TO 2
IF (S.LT.RPR(I,3)) GO TO 1
C1=RPR(I,2)
C2=RPR(I,18)
GO TO 3
1 C1=RPR(I,7)
C2=RPR(I,8)
GO TO 3
2 C1=RPR(I,5)
C2=RPR(I,6)
3 AR=C1*8+C2
RETURN
END
C SUBROUTINE FOR OUTPUT SIMULATED HYDROLOGY
SUBROUTINE OTPTS(FMTA,FMTB,K,J)
COMMON/BLK1/AREA(7,4)
COMMON AJST(7), QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
1ACOR(7), CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
3RPR(7,18),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QGRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
6,CMT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
COMMON ACR, AJ80,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LVR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSH,NRVR,NSIC,NSB,NSH,NVR,
2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
3IPR,IUL, LYRO,CAP(1818),NUMENT,CAPG(1788),NUGNT,C(38,13,45)
1,NVR,INAF,
7VAR(41,12,7,13)
DIMENSION FMTA(4),FMTB(4)
IF (IUL.GT.0) NSB=NSB-1
L1=1
L2=2
L13=13
WRITE(IOUT,200) LVR,K
200 FORMAT(/1X,3H L=15,5X,3H K=13)
2 WRITE(IOUT,202) ((SBNM(I,L),L=1,2),I=1,NSB)
202 FORMAT(7H ITEM ,9(1X,2A4))
WRITE(IOUT,FMTA) OTLV(1), (VAR(J,K,I,L1),I=1,NSB)

```

```

      WRITE(IOUT,FMTB) OTLV(2),(VAR(J,K,I,L2),I=1,NSB)
      WRITE(IOUT,FMTB) OTL(1),(SIM(I,1),I=1,NSB)
      WRITE(IOUT,FMTB) OTLV(3),(VAR3(I),I=1,NSB)
      DO 4 L=2,NSB
4     WRITE(IOUT,FMTB) OTL(L),(SIM(I,L),I=1,NSB)
      WRITE(IOUT,FMTB) OTLV(4),(VAR(J,K,I,L13),I=1,NSB)
      IF(IUL.GT.0) NSB=NSB+1
      RETURN
END
C     SUBROUTINE FOR OUTPUT RESERVOIR OPERATION
      SUBROUTINE OTPTR (K)
      COMMON/BLK1/AREA(7,4)
      COMMON AJST(7)
      1ACOR(7), CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
      2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
      3RPR(7,10),RVAR(4,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
      4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
      5FMT3(4),FMT4(4),QGRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
      6,CMT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON ACR, AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
      1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
      2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
      3IPR,IUL, LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
      1,NYR,INAF,
      7VAR(41,12,7,13)
      IF(INAF.LT.3) GO TO 100
      WRITE(IOUT,101) LYR,K
101  FORMAT(/1X,3HL =,15,5X,3HK =,13)
100  NRS=0
      DO 1 I=1,NSB
      1 NRS=NRS+IND(I,5)
      IF(NRS.EQ.0) GO TO 4
      WRITE(IOUT,200)
200  FORMAT(/1X,9HRESERVOIR)
      WRITE(IOUT,202) (ROTL(L),L=1,NRSM)
202  FORMAT(/9H SUB BSN,7(5XA4),4X,4HAJST)
      DO 3 I=1,NSB
      IF(IND(I,5).EQ.0) GO TO 3
      WRITE(IOUT,203) (SBNM(I,L),L=1,2),(RSIM(I,L),L=1,NRSM),AJST(I)
203  FORMAT(1X,2A4,7F9.0,F8.0)
      3 CONTINUE
      4 RETURN
      END
C     SUBROUTINE = MODEL OF UTAH LAKE
      SUBROUTINE LAKE
C ***
C *** THIS PROGRAM IS WRITTEN TO DUPLICATE THE PROJECT OPERATION STUDY
C *** FOR UTAH LAKE AS IT WAS DONE IN THE 1964 DEFINITE PLAN REPORT
C *** THE STUDY ASSUMES THAT BOTH PROVO AND GOSHEN BAY DIKES ARE
C *** CONSTRUCTED AND IN OPERATION AS PLANNED
C ***
      COMMON/JOBTIT/ TITLE(12),IPAGE
      COMMON AJST(7)
      1ACOR(7), CAF(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
      2IND(7,5),OTL(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
      3RPR(7,10),RVAR(4,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,18),
      4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
      5FMT3(4),FMT4(4),QGRY(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
      6,CMT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON ACR, AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
      1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
      2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
      3IPR,IUL, LYRO,CAP(1810),NUMENT,CAPG(1780),NUGNT,C(30,13,45)
      1,NYR,INAF,
      7VAR(41,12,7,13)
      DIMENSION MONTH(13), TOTAL(33,41), SUMTOT(33), AVE(33),
      1AREAS(1810), TOMD(2), SPILLS(20), AREASG(1780), DMND(2,13),
      2ELEV(11), QDG(10,11), CH(10), TABLE(17), KARD(14), QRTN(13),
      3WEVP(13,41), HISA(13,41), APPT(13,41), BPPT(13,41), PPT(13,41)
      4,CPPT(4)
      DATA MONTH/3HSEP,3HOCT,3HNOV,3HDEC,3HJAN,3HFEB,3HMAR,3HAPR,3HMY,
      13HJUN,3HJUL,3HAUG,3HSEP/
C ***
C *** THIS DATA STATEMENT IS AN ARRAY OF DIFFERENCES IN ELEVATION

```

```

C *** BETWEEN THE DIKED LAKE AND GOSHEN BAY
C ***
      DATA TABLE/4,,3.5,3,,2.5,2,,1.5,1,,0.5,0,,-0.5,-1,,-1.5,-2,,-2.5,
      1-3,,-3.5,-4./
C ***
C *** THIS TITLE APPEARS AT THE TOP OF EACH PAGE OF OUTPUT
C ***
      AREA=ELEGOS((C(22,L,K)),KKX)
      READ(5,10) TITLE
      10 FORMAT(12A6)
C ***
C *** CTDS = CONVERSION OF PPM TO A DESIRED UNIT
C *** GWSC = GROUND WATER SALT CONTENT
C *** SDEAD = DEAD STORAGE IN UTAH LAKE , ACRE-FEET
C *** NUNENT = THE NUMBER OF VALUES IN THE DIKED LAKE AREA-CAPACITY
C *** TABLES
C *** NUGNT = THE NUMBER OF VALUES IN THE GOSHEN BAY AREA-CAPACITY
C *** TABLES
C *** KPPT= THE NUMBER OF STATIONS USED TO CALCULATED THE PRECIPITATION
C *** ON UTAH LAKE
C ***
C *** DLS = A DUMMY LAKE STORAGE USED TO CALCULATE TDS WHEN THE LAKE
C *** CONTENT REACHES ZERO
      READ(5,979) CTDS,GWSC,SDEAD,NUNENT,NUGNT,KPPT,DLS
979  FORMAT(F8.0,F5.0,F8.2, 3I5,F5.1)
C ***
C *** THE FOLLOWING PORTION OF THE PROGRAM READS AND CALCULATES THE
C *** WEIGHTED PRECIPITATION FOR THE DIKED LAKE IN FEET
C *** CPPT(M) = THE WEIGHTING FACTOR TO BE APPLIED TO EACH PRECIPITATION
C *** STATION
C ***
      DO 400 K=1,NYR
      DO 400 L=2,13
400  APPT(L,K)=0.0
      READ(5,403) (CPPT(M),M=1,KPPT)
403  FORMAT(8F10.0)
      DO 402 M=1,KPPT
      READ(5,401) ((BPPT(I,J),I=2,13),J=1,NYR)
401  FORMAT(8X,12F6.2)
      DO 402 K=1,NYR
      DO 402 L=2,13
402  APPT(L,K)=APPT(L,K)+BPPT(L,K)*CPPT(M)/12.
C ***
C *** THIS STATEMENT READS THE INITIAL CONDITIONS FOR COLUMNS 14 ,13,
C *** 21, 20, AND 29
C ***
      READ(5,12) C(14,1,1), C(13,1,1), C(21,1,1), C(20,1,1), C(29,1,1)
12  FORMAT(4F6.1,F10.0)
13  FORMAT(8X,12F6.1)
37  FORMAT(8X,12F6.2)
      READ(5,14,ERR=1000) (AREAS(J), J=1,NUNENT)
      READ(5,14,ERR=1000) (CAP (J), J=1,NUNENT)
      READ(5,14,ERR=1000) (AREASG(J),J=1,NUGNT)
      READ(5,14,ERR=1000) (CAPG (J), J=1,NUGNT)
      READ(5,14,ERR=1000) (SPILLS(J),J=1,17)
14  FORMAT(10F6.1)
      READ(5,91,ERR=1000) (CH(J),J=1,10)
      READ(5,91,ERR=1000) (ELEV(J),J=1,11)
91  FORMAT(12F6.2)
      DO 98 M=1,10
      READ(5,92,ERR=1000) (QDG(M,N),N=1,11)
92  FORMAT(11F5)
98  CONTINUE
      DO 701 K=1,NYR
      DO 702 J=1,30
      TOTAL(J,K)=0.0
702  CONTINUE
701  CONTINUE
C ***
C *** ALL CALCULATIONS WITHIN THE PROGRAM DEFINE VALUES IN THE FORMAT
C *** C(J,L,K) WHICH STANDS FOR A COLUMN NUMBER 'J', A MONTH 'L', AND
C *** YEAR 'K'
C *** C(1,L,K) = PROVO RIVER INFLOW TO UTAH LAKE
C *** C(2,L,K) = OTHER GAGED STREAM INFLOWS TO UTAH LAKE

```

```

C *** C(3,L,K) = OTHER UNGAGED STREAM INFLOWS TO UTAH LAKE
C *** C(4,L,K) = GROUNDWATER INFLOW TO UTAH LAKE
C *** C(5,L,K) = TOTAL INFLOW TO UTAH LAKE = COLUMNS 1 + 2 + 3 + 4
C *** C(6,L,K) = THE AMOUNT OF JORDAN RIVER DEMAND THAT CAN BE
C *** SUPPLIED
C *** C(7,L,K) = THE SHORTAGE FOR JORDAN RIVER SUPPLY
C *** C(8,L,K) = THE AMOUNT OF MOSIDA AREA DEMAND THAT CAN BE
C *** SUPPLIED
C *** C(9,L,K) = THE SHORTAGE FOR MOSIDA AREA SUPPLY
C *** C(10,L,K) = EVAPORATION FROM THE DIKED LAKE
C *** C(11,L,K) = INCREMENTAL CONSUMPTIVE USE = USED TO MODIFY THE
C *** INFLOW TO REFLECT CURRENT OPERATION
C *** C(12,L,K) = SPILLS TO JORDAN RIVER
C *** C(13,L,K) = END OF MONTH ACTIVE CONTENT IN THE DIKED LAKE
C *** C(14,L,K) = END OF MONTH WATER SURFACE AREA FOR THE DIKED LAKE
C *** C(15,L,K) = WATER SURFACE ELEVATION IN THE DIKED LAKE AS IT
C *** RELATES TO COMPROMISE ELEVATION
C *** C(16,L,K) = GOSHEN BAY INFLOW WITHHELD FROM UTAH LAKE BY DIKING
C *** C(17,L,K) = SPILLS INTO GOSHEN BAY FROM UTAH LAKE
C *** C(18,L,K) = TOTAL INFLOW TO GOSHEN BAY
C *** C(19,L,K) = EVAPORATION FROM GOSHEN BAY
C *** C(20,L,K) = END OF MONTH CONTENT IN GOSHEN BAY
C *** C(21,L,K) = END OF MONTH WATER SURFACE AREA FOR GOSHEN BAY
C *** C(22,L,K) = WATER SURFACE ELEVATION IN GOSHEN BAY AS IT RELATES
C *** TO COMPROMISE ELEVATION
C *** C(23,L,K) = PROVO RIVER TDS INFLOW TO UTAH LAKE
C *** C(24,L,K) = OTHER STREAM TDS INFLOW TO UTAH LAKE
C *** C(25,L,K) = GROUNDWATER TDS INFLOW TO UTAH LAKE
C *** C(26,L,K) = TOTAL TDS INFLOW TO UTAH LAKE
C *** C(27,L,K) = TOTAL TDS OUTFLOW FROM UTAH LAKE
C *** C(28,L,K) = END OF MONTH TDS PPM IN UTAH LAKE
C *** C(29,L,K) = END OF MONTH TDS CONTENT IN UTAH LAKE
C *** C(30,L,K) = CHANGE IN TDS CONTENT DURING THE MONTH
C ***
C *** WRITE(6,600)
600 FORMAT(1H1,5X,'THE FOLLOWING DATA ARE CONSTANT FOR EACH YEAR')
READ(5,13,ERR=1000) ((DMND(I,J),J=2,13),I=1,2)
DO 500 I=1,2
  TDMD(I)=0.
DO 500 J=2,13
  TDMD(I)=TDMD(I)+DMND(I,J)
WRITE(6,601)
601 FORMAT(//8X,'DEMAND FOR JORDON RIVER')
WRITE(6,602) (MONTH(J),J=2,13)
602 FORMAT(8X,12(5X,A3),4X,'ANNUAL')
WRITE(6,603) (DMND(I,J),J=2,13),TDMD(1)
603 FORMAT(8X,12F8.1,F10.1)
WRITE(6,604)
604 FORMAT(//8X,'DEMAND FOR MOSIDA AREA')
WRITE(6,602) (MONTH(J),J=2,13)
WRITE(6,603) (DMND(2,J),J=2,13),TDMD(2)
READ(5,13,ERR=1000) (QRTN(J),J=2,13)
TRTN=0.
DO 501 J=2,13
  TRTN=TRTN+QRTN(J)
WRITE(6,605)
605 FORMAT(//8X,'RETURN FLOW FROM MOSIDA AREA')
WRITE(6,602) (MONTH(J),J=2,13)
WRITE(6,603) (QRTN(J),J=2,13),TRTN
READ(5,37,ERR=1000) ((WEVP(I,J),I=2,13),J=1,NYR)
READ(5,13,ERR=1000) ((HISA(I,J),I=2,13),J=1,NYR)
READ(5,13,ERR=1000) ((C(10,I,J),I=2,13),J=1,NYR)
GO TO 978
1000 READ(10,980) (KARD(L),L=1,14)
980 FORMAT(13A6,A2)
WRITE(6,998) (KARD(L),L=1,14)
998 FORMAT('0', 'THE FOLLOWING CARD IS IN ERROR, PLEASE EXAMINE YOUR DA
1TA',//10X,13A6,A2)
9 STOP ERROR
C ***
C *** THIS STATEMENT BEGINS THE DO LOOP FOR EACH YEAR
C ***
978 DO 980 K=1,NYR
98065 FORMAT( )

```

```

C ***
C *** THIS STATEMENT BEGINS THE DO LOOP FOR EACH MONTH
C ***
DO 999 M=2,13
  L=M
  LCNT=0
  C(14,L,K) = C(14,L=1,K)
  2 AVGA=(C(14,L,K)+C(14,L=1,K))/2.
  LCNT = LCNT+1
  C(10,L,K) = WEVP(L,K)*AVGA
  PPT(L,K)=APPT(L,K)*AVGA
  ADIF=AVGA-HISA(L,K)
  CDIF=0.35*WEVP(L,K)
  C(5,L,K) = C(1,L,K) + C(2,L,K) + C(3,L,K) + C(4,L,K)
  C(11,L,K) = ADIF*CDIF
  C(13,L,K) = C(13,L=1,K)+C(5,L,K)-DMND(1,L)-DMND(2,L)-C(10,L,K)+
  1C(11,L,K) + PPT(L,K)
  40 IF(C(13,L,K).GT.629.2) GO TO 800
  IF(C(13,L,K).LT=-12.5) GO TO 3
C ***
C *** THE FOLLOWING PORTION OF THE PROGRAM MAKES CALCULATIONS IF ACTIVE
C *** EDM CONTENT IS BETWEEN 629,200 ACRE FEET AND -12,500 ACRE FEET
C ***
  CALL CAPUTL((C(13,L,K)),CAPUTL,KXX)
  C(15,L,K)=CAPUTL
  IF(C(15,L,K).LE.-7.5) C(15,L,K) = C(15,L,K) + 0.5
  AREA=ELEUTL((C(15,L,K)),KXX)
  IF(LCNT.GE.5) C(14,L,K) = AREA
  IF(AREA.EQ.C(14,L,K)) GO TO 41
  C(14,L,K) = AREA
  GO TO 2
  41 LCNT=0
  IF(C(13,L,K).GE.0.0) GO TO 42
C ***
C *** THE FOLLOWING PORTION OF THE PROGRAM MAKES CALCULATIONS IF ACTIVE
C *** EDM CONTENT IS LESSER THAN 0 ACRE FEET
C ***
  3 AVGA=(C(14,L,K)+C(14,L=1,K))/2.
  C(10,L,K) = WEVP(L,K)*AVGA
  PPT(L,K)=APPT(L,K)*AVGA
  ADIF=AVGA-HISA(L,K)
  LCNT = LCNT + 1
  C(11,L,K) = ADIF*CDIF
  C(13,L,K) = C(13,L=1,K) + C(5,L,K) - C(10,L,K) + C(11,L,K)
  1 + PPT(L,K)
  IF(C(13,L,K).LT.-12.5) GO TO 55
  51 CALL CAPUTL((C(13,L,K)),CAPUTL,KXX)
  C(15,L,K)=CAPUTL
  IF(C(15,L,K).LT.-7.5) C(15,L,K) = C(15,L,K) + 0.5
  AREA=ELEUTL((C(15,L,K)),KXX)
  IF(LCNT.GE.5) C(14,L,K) = AREA
  IF(AREA.EQ.C(14,L,K)) GO TO 52
  C(14,L,K) = AREA
  GO TO 3
  52 IF(C(13,L,K).LT.0.0) GO TO 53
  C(15,L,K) = -12.5
  C(14,L,K) = 33.0
  AVGA=(C(14,L,K)+C(14,L=1,K))/2.
  C(10,L,K) = WEVP(L,K)*AVGA
  PPT(L,K)=APPT(L,K)*AVGA
  ADIF=AVGA-HISA(L,K)
  C(11,L,K) = ADIF*CDIF
  C(13,L,K) = C(13,L=1,K) + C(5,L,K) - C(10,L,K) + C(11,L,K)
  1 + PPT(L,K)
  GO TO 54
  55 C(15,L,K) = -13.3
  C(14,L,K) = 0.0
  AVGA=(C(14,L,K) + C(14,L=1,K))/2.
  C(10,L,K) = WEVP(L,K)*AVGA
  PPT(L,K)=APPT(L,K)*AVGA
  ADIF=AVGA-HISA(L,K)
  C(11,L,K) = ADIF*CDIF
  C(13,L,K) = C(13,L=1,K) + C(5,L,K) - C(10,L,K) + C(11,L,K)
  1 + PPT(L,K)

```

```

      IF(C(13,L,K).LT.-12.5) GO TO 56
      GO TO 51
C ***
C *** THE FOLLOWING PORTION OF THE PROGRAM MAKES CALCULATIONS IF ACTIVE
C *** EOM CONTENT IS GREATER THAN 629,200 ACRE-FEET
C ***
      C(13,L,K) = C(13,L-1,K) + C(5,L,K) - C(10,L,K) + C(11,L,K)
      1 + PPT(L,K)
      CALL CAPUTY((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K)=CAPUTL
      AVERAGE = (C(15,L,K) + C(15,L-1,K)) /2.0
      C(12,L,K) = SPILL(AVERAGE)
      DAYS = DAYMON(L,K)
      IF(C(12,L,K).GT.1500.) GO TO 81
      C(12,L,K) = C(12,L,K) + 1.98 * DAYS * .001
      TOTDMD = DMND(1,L)+DMND(2,L)
      IF (C(12,L,K) .GE. TOTDMD) GO TO 82
      GO TO 31
      81 C(12,L,K) =(1500.0) * 1.98 * DAYS * .001
      82 C(13,L,K) = C(13,L,K) - C(12,L,K)
      C(12,L,K) = C(12,L,K) - DMND(1,L) - DMND(2,L)
      IF(C(13,L,K).GT.629.2) GO TO 84
      AREA = 0.0
      IF(LCNT.GE.5) C(14,L,K) = AREA
      IF(AREA.EQ.C(14,L,K)) GO TO 83
      C(14,L,K) = AREA
      GO TO 2
      84 CALL CAPUTY((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K)=CAPUTL
      AREA=ELEUTL((C(15,L,K)),KXX)
      IF(LCNT.GE.5) C(14,L,K) = AREA
      IF(AREA.EQ.C(14,L,K)) GO TO 8555
      C(14,L,K) = AREA
      GO TO 2
C ***
C *** AFTER CALCULATING VALUES FOR THE DIKED LAKE ABOVE, THE FOLLOWING
C *** PORTION OF THE PROGRAM MAKES CALCULATIONS PERTINENT TO GOSHEN BAY
C ***
      85 C(10,L,K) = C(10,L,K) + QRTN(L)
      C(21,L,K) = C(21,L-1,K)
      9999 AVGB=(C(21,L,K)+C(21,L-1,K))/2.
      C(19,L,K) = WEVP(L,K)*AVGB
      C(20,L,K) = C(10,L,K) + C(19,L,K) + C(20,L-1,K)
      IF(C(20,L,K).LT.0.0) C(20,L,K) = 0.01
      CALL CAPGOS((C(20,L,K)),CAPGOS,KXX)
      C(22,L,K)=CAPGOS
      AREA=ELEGOS((C(22,L,K)),KXX)
      LCNT = LCNT + 1
      IF(LCNT.GE.5) C(21,L,K) = AREA
      IF(AREA.EQ.C(21,L,K)) GO TO 9988
      C(21,L,K) = AREA
      GO TO 9999
      9988 TESTCH = C(15,L,K) - C(22,L,K)
      IF (TESTCH.GT.0.1.AND.C(13,L,K).GT.629.2) GO TO 997
      GO TO 899
      997 C(17,L,K) = EGL(TESTCH,C(13,L,K) )
      LCNT = 0
      C(17,L,K) = C(17,L,K) + 1.98 * DAYS * .001
      C(10,L,K) = C(10,L,K) + C(17,L,K) + QRTN(L)
      C(21,L,K) = C(21,L-1,K)
      8554 AVGB=(C(21,L,K)+C(21,L-1,K))/2.
      C(19,L,K) = WEVP(L,K)*AVGB
      C(20,L,K) = C(20,L-1,K) + C(10,L,K) - C(19,L,K)
      IF(C(20,L,K).LT.0.0) C(20,L,K) = 0.01
      CALL CAPGOS((C(20,L,K)),CAPGOS,KXX)
      C(22,L,K)=CAPGOS
      AREA=ELEGOS((C(22,L,K)),KXX)
      LCNT = LCNT + 1
      IF(LCNT.GE.5) C(21,L,K) = AREA
      IF(AREA.EQ.C(21,L,K)) GO TO 921
      C(21,L,K) = AREA
      GO TO 8554
      921 DIFEOM = C(13,L,K) - C(17,L,K)
      IF(DIFEOM.GE.629.2) GO TO 922

```

```

      C(13,L,K) = 629.2
      C(17,L,K) = C(13,L,K) - DIFEOM
      C(10,L,K) = C(10,L,K) + C(17,L,K) + QRTN(L)
      C(21,L,K) = C(21,L-1,K)
      920 AVGB=(C(21,L,K)+C(21,L-1,K))/2.
      C(19,L,K) = WEVP(L,K)*AVGB
      C(20,L,K) = C(20,L-1,K) + C(10,L,K) - C(19,L,K)
      IF(C(20,L,K).LT.0.0) C(20,L,K) = 0.01
      CALL CAPGOS((C(20,L,K)),CAPGOS,KXX)
      C(22,L,K)=CAPGOS
      LCNT = LCNT + 1
      IF(LCNT.GE.5) C(21,L,K) = AREA
      IF(AREA.EQ.C(21,L,K)) GO TO 923
      C(21,L,K) = AREA
      GO TO 920
      922 C(13,L,K) = DIFEOM
      C(0,L,K) = DMND(1,L)
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = 0.0
      C(9,L,K) = 0.0
      CALL CAPUTY((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K)=CAPUTL
      LCNT = 0
      GO TO 899
      923 LCNT = 0
      C(0,L,K) = DMND(1,L)
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = 0.0
      C(9,L,K) = 0.0
      GO TO 899
      83 C(10,L,K) = 629.2
      C(0,L,K) = DMND(1,L)
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = 0.0
      C(9,L,K) = 0.0
      C(12,L,K) = C(13,L-1,K) + C(5,L,K) - DMND(1,L) - DMND(2,L) -
      1 C(10,L,K) - C(13,L,K) + C(11,L,K) + PPT(L,K)
      C(10,L,K) = 0.0
      LCNT = 0
      GO TO 85
      8555 LCNT = 0
      C(0,L,K) = DMND(1,L)
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = 0.0
      C(9,L,K) = 0.0
      GO TO 85
      42 C(0,L,K) = DMND(1,L)
      C(8,L,K) = DMND(2,L)
      C(7,L,K) = 0.0
      C(9,L,K) = 0.0
      CALL CAPUTY((C(13,L,K)),CAPUTL,KXX)
      C(15,L,K)=CAPUTL
      GO TO 85
      53 C(0,L,K) = 0.0
      C(8,L,K) = 0.0
      C(7,L,K) = DMND(1,L)
      C(9,L,K) = DMND(2,L)
      C(12,L,K) = 0.0
      C(10,L,K) = C(10,L,K) - 0.5
      LCNT = 0
      GO TO 85
      54 C(0,L,K) = (DMND(1,L)/(DMND(1,L)+DMND(2,L)))*(C(13,L,K))
      C(8,L,K) = (DMND(2,L)/(DMND(1,L)+DMND(2,L)))*(C(13,L,K))
      C(7,L,K) = DMND(1,L) - C(0,L,K)
      C(9,L,K) = DMND(2,L) - C(0,L,K)
      C(13,L,K) = 0.0
      LCNT = 0
      GO TO 85
      56 C(10,L,K) = C(13,L-1,K) + C(5,L,K) +12.5 + CDIF + PPT(L,K)
      C(13,L,K) = -12.5
      C(0,L,K) = 0.0
      C(7,L,K) = DMND(1,L)
      C(8,L,K) = 0.0
      C(9,L,K) = DMND(2,L)

```

```

C(13,L,K) = -12.5
C(15,L,K) = 0.0
LCNT = 0
GO TO 85
31 C(13,L,K) = C(13,L-1,K) + C(5,L,K) - DMND(1,L) - DMND(2,L) -
1C(10,L,K) + C(11,L,K) + PPT(L,K)
CALL CAPUTL(C(13,L,K)),CAPUTL,XXX)
C(15,L,K) = CAPUTL
AVERAGE = (C(15,L,K) + C(15,L-1,K))/2.0
C(12,L,K) = SPILL(AVERAGE)
DAYS = DAYMON(L,K)
IF(C(12,L,K).GT. 1500.0) GO TO 34
C(12,L,K) = C(12,L,K)+1.98*DAYS*.001
GO TO 35
34 C(12,L,K) = (1500.0)+1.98*DAYS*.001
35 DLEFT = C(13,L,K) - 629.2
IF(DLEFT.GE. C(12,L,K)) GO TO 32
C(12,L,K) = DLEFT
32 C(13,L,K) = C(13,L,K) - C(12,L,K)
C(6,L,K) = DMND(1,L)
C(8,L,K) = DMND(2,L)
C(7,L,K) = DMND(1,L) - C(6,L,K)
C(9,L,K) = DMND(2,L) - C(8,L,K)
GO TO 85
899 C(23,L,K) = TDS1(C(1,L,K),L)
DOTHRC(C(2,L,K)+C(3,L,K))
C(24,L,K)=TDS2(DOTHRC,L)
C(25,L,K)=CTDS*GWSC+C(4,L,K)
C(26,L,K)=C(23,L,K)+C(24,L,K)+C(25,L,K)
TDS=C(13,L,K)+C(12,L,K)+C(6,L,K)+C(8,L,K)+C(17,L,K)+SDEAD
IF(TDS.LE.0.0) TDS=DL8
C(28,L,K) = ((C(26,L,K)+C(29,L-1,K))/TDS)/CTDS
C(27,L,K)=CTDS*C(26,L,K)*(C(12,L,K)+C(6,L,K)+C(17,L,K))
8TH=SDEAD + C(13,L,K)
IF(8TH.LE.0.0) 8TH=DL8
C(29,L,K)=CTDS*C(28,L,K)+8TH
C(30,L,K)=C(29,L,K)-C(29,L-1,K)
C ***
C *** THIS IS THE END OF THE DO LOOP FOR EACH MONTH
C ***
999 CONTINUE
715 DO 901 L=2,13
DO 902 J=1,30
ROUND = 0.5
IF(C(J,L,K).LT.0.0) ROUND = -0.5
IF(J.EQ.10) GO TO 777
IF(J.EQ.19) GO TO 777
IF(J.EQ.15) GO TO 777
IF(J.EQ.22) GO TO 777
C(J,L,K) = FLOAT(INT(C(J,L,K)*10.0 + ROUND )) / 10.0
777 TOTAL(J,K) = TOTAL(J,K) + C(J,L,K)
902 CONTINUE
901 CONTINUE
DO 903 IL = 1,30
C(IL,1,K+1) = C(IL,13,K)
903 CONTINUE
KK=K
C ***
C *** THIS IS THE END OF THE DO LOOP FOR EACH YEAR
C ***
900 CONTINUE
C ***
C *** THE REMAINING PORTION OF THIS PROGRAM SUMS, AVERAGES, AND PRINTS
C *** THE VALUES IN TABULAR FORM
C ***
DO 703 L=1,30
SUMTOT(L) = 0.0
703 CONTINUE
DO 904 K=1,KK
DO 905 L=1,30
SUMTOT(L) = SUMTOT(L) + TOTAL(L,K)
905 CONTINUE
904 CONTINUE
DO 906 I=1,30

```

92

```

AVE(I) = SUMTOT(I) / FLOAT(KK)
906 CONTINUE
4 DO 5 I=1,NYR
CALL TITLES(1)
WRITE(6,100)
WRITE(6,101)
100 FORMAT(38X,'MINIMUM DRAWDOWNLEVEL AT 12.0 FEET BELOW COMPROMISE',
1/,53X,'(UNITS: 1,000 ACRE-FEET)')
101 FORMAT(' ',130('='),
1/,11X,68('='), 'UTAH LAKE OPERATION WITH PROVO AND GOSHEN BAYS DIKE
2D',10('='),
3//12X,'1',6('='), 'INFLOWS TO UTAH LAKE',6('='), '1',2X,'1', 'JORDAN R
4,--',2X,'1', 'MOSIDA A,--',2X,'1',12('='), 'THE DIKED UTAH LAKE',
512('='), '1', '3X', 'MONTH',90X, 'SPILL',2X, 'ACTIVE',3X, 'EOM',
6/,4X, 'AND',5X, 'PROVO',2X, 'OTHER',2X, 'OTHER',1X, 'GROUND',3X, 'TOTAL'
7,5X, 'SUPP',2X, 'SHOR',5X, 'SUPP',2X, 'SHOR',5X, 'W.S.',2X, 'INCR',
8,3X, 'TO',6X, 'EOM',4X, 'W.S.',4X, 'W.S.', '3X, 'YEAR',4X, 'RIVER',2X,
9'GAGED',2X, 'UNGAG',2X, 'WATER',3X, 'INFLO',6X, 'LIED',3X, 'TAGE',
16X, 'LIED',3X, 'TAGE',5X, 'EVP',3X, 'CONS',2X, 'JORDN',3X, 'CONT',3X,
2'AREA',4X, 'ELEV',
3/,127('='),
4/,14X,'1',6X,'2',6X,'3',6X,'4',7X,'5',9X,'6',6X,'7',9X,'8',6X,'9',
58X,'10',5X,'11',5X,'12',6X,'13',5X,'14',5X,'15',
6/,127('='))
DO 6 J=2,13
IYR = LYRD + I
IF(J.LE.4) IYR = IYR - 2
IF(J.GT.4) IYR = IYR - 1
99 WRITE(6,102) MONTH(J),IYR, (C(K,J,I),K=1,15)
102 FORMAT(' ',A3,2X,I4,4F7.1,F8.1,3X,2F7.1,3X,2F7.1,2X,3F7.1,F8.1,
1F7.1,F8.2)
6 CONTINUE
WRITE(6,207)
207 FORMAT(' ',130('='))
WRITE(6,100) (TOTAL(K,I),K=1,12)
WRITE(6,103)
103 FORMAT(' ',//)
WRITE(6,100)
109 FORMAT(' ',130('='),
1/,11X,42('='),
2//,12X,'1',16('='), 'THE GOSHEN BAY',17('='), '1',4X,'1',6('='),
3'TDS INFLOW AND OUTFLOW',7('='), '1',3X,'1',3('='), 'UTAH LAKE TDS',
43('='), '1', '3X', 'MONTH',12X, 'SPIL',25X, 'EOM',37X, 'TOTAL',3X,
5'TOTAL',5X, 'EOM',4X, 'EOM',4X, 'CHNGE', '4X, 'AND',5X, 'GOS,B',3X,
6'FROM',3X, 'TOTAL',3X, 'W.S.',3X, 'EOM',4X, 'W.S.',4X, 'W.S.',6X,
7'PROVO',2X, 'OTHER',1X, 'GROUND',4X, 'IN',3X, 'R. OUT',5X, 'TDS',4X,
8'TDS',6X, 'IN', '3X, 'YEAR',5X, 'INFLO',3X, 'U.L.',3X, 'INFLO',3X, 'EVP',
9,3X, 'CONS',3X, 'AREA',4X, 'ELEV',6X, 'RIVER',2X, 'STRENT',2X, 'WATER',
14X, 'FLOW',3X, 'FLOW',6X, 'PPM',3X, 'CONT',5X, 'TDS', '127('='),
2/,14X,'16',5X,'17',6X,'18',5X,'19',5X,'20',5X,'21',5X,'22',10X,
3'23',5X,'24',5X,'25',6X,'26',6X,'27',6X,'28',6X,'29',6X,'30',
4/,127('='))
DO 66 J=2,13
IYR = LYRD + I
IF(J.LE.4) IYR = IYR - 2
IF(J.GT.4) IYR = IYR - 1
WRITE(6,302) MONTH(J),IYR, (C(K,J,I),K=16,30)
302 FORMAT(' ',A3,2X,I4,2F7.1,F8.1,3F7.1,F8.2,4X,3F7.0,5F8.0)
66 CONTINUE
WRITE(6,207)
WRITE(6,300) (TOTAL(K,I),K=16,19), (TOTAL(K,I),K=23,27),
1(TOTAL(30,I))
100 FORMAT(' ',1X,'WY TOTAL',4F7.1,F8.1,3X,2F7.1,2X,2F7.1,2X,3F7.1)
300 FORMAT(' ',1X,'WY TOTAL',2F7.1,F8.1,F7.1,26X,3F7.0,2F8.0,16X,F8.0)
5 CONTINUE
CALL TITLES(1)
WRITE(6,100)
WRITE(6,101)
DO 88 I=1,NYR
IYR = LYRD + I - 1
WRITE(6,105) IYR, (TOTAL(J,I),J=1,12)
105 FORMAT(' ',5X,I4,4F7.1,F8.1,3X,2F7.1,2X,2F7.1,2X,3F7.1)
88 CONTINUE
WRITE(6,207)

```

```

      WRITE(6,106) (SUMTOT(J),J=1,12)
106  FORMAT(' ',4X,'TOTAL',4F7.1,F8.1,3X,2F7.1,2X,2F7.1,2X,3F7.1)
      WRITE(6,107) (AVE(J),J=1,12)
107  FORMAT(' ',2X,'AVERAGE',4F7.1,F8.1,3X,2F7.1,2X,2F7.1,2X,3F7.1)
      CALL TITLES(1)
      WRITE(6,100)
      WRITE(6,109)
      DO 888 I=1,NYR
      IYR = LYRO + I - 1
      WRITE(6,305) IYR, (TOTAL(J,I),J=16,19), (TOTAL(J,I),J=23,27),
1 (TOTAL(30,I))
305  FORMAT(' ',5X,14,2F7.1,F8.1,F7.1,26X,3F7.0,2F8.0,16X,F8.0)
888  CONTINUE
      WRITE(6,207)
      WRITE(6,306) ((SUMTOT(J),J=16,19), (SUMTOT(J),J=23,27),
1 (SUMTOT(30)))
306  FORMAT(' ',4X,'TOTAL',2F7.1,F8.1,F7.1,26X,3F7.0,2F8.0,16X,F8.0)
      WRITE(6,307) ((AVE(J),J=16,19), (AVE(J),J=23,27), (AVE(30)))
307  FORMAT(' ',2X,'AVERAGE',2F7.1,F8.1,F7.1,26X,3F7.0,2F8.0,16X,F8.0)
      WRITE(6,208)
208  FORMAT(1H1)
      STOP
C*****
C *** THIS FUNCTION SUB-PROGRAM WILL RETURN THE TDS CONTENT OF THE
C *** PROVO RIVER
C*****
      FUNCTION TDS1(Q1,L)
      GO TO (2,2,3,3,3,7,9,10,11,12,13),L
2 TDS1=Q1*CTDS*288.0
      RETURN
3 TDS1=Q1*CTDS*281.0
      RETURN
7 TDS1=Q1*CTDS*361.9
      RETURN
9 TDS1=Q1*CTDS*218.1
      RETURN
10 TDS1=Q1*CTDS*247.5
      RETURN
11 TDS1=Q1*CTDS*284.3
      RETURN
12 TDS1=Q1*CTDS*295.2
      RETURN
13 TDS1=Q1*CTDS*293.3
      RETURN
C*****
C *** THIS FUNCTION SUB-PROGRAM WILL RETURN THE TDS CONTENT OF THE
C *** UTAH LAKE DRAINAGE AREA LESS PROVO RIVER
C*****
      FUNCTION TDS2(Q2,L)
      GO TO (2,2,2,2,2,2,3,3,3,3),L
2 TDS2=Q2*CTDS*795.3
      RETURN
3 TDS2=Q2*CTDS*593.2
      RETURN
C ***
C *** THIS FUNCTION SUB-PROGRAM WITH ARGUMENTS ELVA AND KXX RETURNS AN
C *** AREA OF UTAH LAKE GIVEN AN ELEVATION 'ELVA' AND A STARTING POINT
C *** 'KXX'
C ***
      FUNCTION ELEUTL(ELVA,KXX)
      DO 7 J=KXX,NUMENT
      KM=J
      EL = -13.35 + (FLOAT(J))* .01
      IF(ELVA.LE.EL) GO TO 8
7 CONTINUE
      KX=NUMENT
      KM=NUMENT
      GO TO 10
8 KM=J
      KX=KM-1
10 PKX=(ELVA-(-13.35+(FLOAT(KX))* .01))/ .01
      AREDF = AREAS(KM) - AREAS(KX)
      ELEUTL = AREAS(KX) + (PKX * AREDF)
      RETURN

```

```

C ***
C *** THIS FUNCTION SUB-PROGRAM WITH ARGUMENTS I AND J RETURNS THE
C *** NUMBER OF DAYS IN MONTH 'II' IN YEAR 'J'
C ***
      FUNCTION DAYMON(I,J)
      GO TO(1,2,1,2,2,3,2,1,2,1,2,2,1), I
1 DAYMON = 30
      RETURN
2 DAYMON = 31
      RETURN
3 DAYMON = 28
      IF(FLOAT((LYRO+K)/4).LT. 0.1) DAYMON = 29
      RETURN
C ***
C *** THIS FUNCTION SUB-PROGRAM WITH ARGUMENT AVERAGE RETURNS THE SPILL
C *** RATE TO JORDAN RIVER BASED ON AVERAGE ELEVATION OF THE LAKE
C *** 'AVERAGE'
C ***
      FUNCTION SPILL(AVERAGE)
      DO 10 J=1,20
      IF(AVERAGE.GE.TABLE(J)) GO TO 11
10 CONTINUE
11 IF(J.EQ.1) GO TO 12
      KL=J
      KX=KL-1
      GO TO 13
12 KX=J
      KL=J
13 PKX=(AVERAGE - TABLE(KX)) / 0.5
      DIFF = SPILLS(KX) - SPILLS(KL)
      SPILL = SPILLS(KX) + PKX * DIFF
      RETURN
C ***
C *** THIS FUNCTION SUB-PROGRAM WITH ARGUMENTS ELVA AND KXX RETURNS
C *** AN AREA OF GOSHEN BAY GIVEN AN ELEVATION 'ELVA' AND A STARTING
C *** POINT 'KXX'
C ***
      FUNCTION ELEGOS(ELVA,KXX)
      DO 417 J=KXX,NUMGT
      KM=J
      ELG = -13.15 + (FLOAT(J)) * .01
      IF(ELVA.LE.ELG) GO TO 418
417 CONTINUE
      KX=NUMGT
      KM=NUMGT
      GO TO 419
418 IF(J.EQ.1) GO TO 4188
      KM = J
      KX = KM-1
      GO TO 419
4188 KM=J
      KX = J
419 PKX =(ELVA-(-13.15+(FLOAT(KX))* .01)) / .01
      AREDF = AREASG(KM) - AREASG(KX)
      ELEGOS = AREASG(KX) + (PKX * AREDF)
      RETURN
C ***
C *** THIS FUNCTION SUB-PROGRAM RETURNS THE SPILLS TO GOSHEN BAY BASED
C *** ON THE DIFFERENCE IN ELEVATION BETWEEN THE DIKED LAKE AND GOSHEN
C *** BAY 'TESTCH' AND THE ELEVATION OF UTAH LAKE 'ELELOR'
C ***
      FUNCTION EQL(TESTCH,ELELOR)
      C(15,L,K) = ELELOR
      DO 435 I=1,10
      M=I
      IF(TESTCH.GE.CH(I).AND.TESTCH.LE.CH(I+1)) GO TO 436
435 CONTINUE
436 DO 437 J=1,11
      N=J
      PP = ELEV(J+1) - ELEV(J)
      IF(C(15,L,K).GE.ELEV(J).AND.C(15,L,K).LE.ELEV(J+1)) GO TO 438
437 CONTINUE
438 X = (QQQ(M,N+1)-QQQ(M,N)/PP) * (C(15,L,K) - ELEV(J)) + QQQ(M,N)
      Y = (QQQ(M+1,N+1)-QQQ(M+1,N)/PP)*(C(15,L,K)-ELEV(J))+QQQ(M+1,N)

```



```

      EQL = (Y-X) * (TESTCH = CH(M)) / (CH(M+1) = CH(M)) + X
      RETURN
      SUBROUTINE TITLES(NO)
      .....
      * THIS SUBROUTINE USED ALONG WITH SUBROUTINE DAY, GIVES 5 VERSIONS *
      * THAT MAY BE USED WITH ALL PROGRAMS TO IDENTIFY THE OUTPUT, AND *
      * ALSO IDENTIFY THE DATA CARDS. *
      *
      *   VERSION 1. CALL TITLES(1)-WRITES THE TITLE,THE JOB NO.,
      *   THE DATE PROCESSED,AND PAGE NO.
      *
      *   VERSION 2. CALL TITLES(2)-WRITES THE TITLE,THE PAGE NO.,
      *   SKIPS A LINE,THEN WRITES THE
      *   JOB NO.,AND DATE PROCESSED.
      *
      *   VERSION 3. CALL TITLES(3)-WRITES THE TITLE,THE DATE
      *   PROCESSED,AND PAGE NO.
      *
      *   VERSION 4. CALL TITLES(4)-WRITES ONLY THE TITLE,CENTERED
      *   ON THE PAGE,AS LONG AS THE TITLE
      *   IS CENTERED IN THE FIRST 60
      *   COLUMNS ON THE CARD.
      *
      *   VERSION 5. CALL TITLES(5)-THIS VERSION IS USED FOR PUNCH
      *   CARD VERIFICATION ONLY. IT WRITES
      *   NOTHING.
      *
      .....
      COMMON/JOBTIT/TITLE(12),IPAGE
      DIMENSION DATE(2)
      CALL DAY(DATE(1),DATE(2))
      IF(ND.GT.1)GO TO 20000
11111 WRITE(6,1010)TITLE,DATE,IPAGE
1010  FORMAT(1H1,10X,10A6,8H JOB NO ,2A6,14H PROCESSED ON ,2A6,
10H PAGE NO. ,I4)
      GO TO 10000
20000 IF(ND.GT.2)GO TO 30000
      WRITE(6,1020)(TITLE(I),I=1,10),IPAGE,(TITLE(I),I=11,12),DATE
1020  FORMAT(1H1,5X,10A6,10H PAGE NO. ,I4/13X,9H (JOB NO ,2A6,
114H PROCESSED ON ,2A6,2H) )
      GO TO 10000
30000 IF(ND.GT.3)GO TO 40000
      WRITE(6,1030)(TITLE(I),I=1,10),DATE,IPAGE
1030  FORMAT(1H1,10X,10A6,20X,14H PROCESSED ON ,2A6,10H PAGE NO. ,I4)
      GO TO 10000
40000 IF(ND.GT.4)GO TO 50000
      WRITE(6,1040)(TITLE(I),I=1,10)
1040  FORMAT(1H1,30X,10A6)
      GO TO 10000
50000 IF(ND.GT.5)GO TO 60000
      GO TO 10000
60000 GO TO 11111
10000 IPAGE=IPAGE+1
      RETURN
      END
      *ASM,IN DAY,DAY
      S(1)
      AXRS
      CALL DAY(A,B)
      *
      *   A IS A 2 WORD ARRAY
      *   B IS IGNORED
      DAY*
      SBL      A3,36
      ER       DATES
      *
      *   THIS MAY HELP LATER
      *   A0 IS MMDDYY
      *   REMOVE ZONE BITS
      *   CLEAR A1
      *   SHIFT FIRST TO A1
      *   SHIFT INTO A2 AND SIZE
      *   MORE ZONE
      *   MOVE THE GOOD PART
      *   FORM THE SUM
      *   LOAD THE ALPHA MONTH
      *   A0= YYYYXD   A1= 1-MMH---
      LDLSL    A0,2
      LSSL     A1,36
      LDSC     A0,4
      M1,U     A1,10
      LDLSL    A0,2
      LDSC     A0,4
      AA       A2,A1
      L        A1,M=1,A2
      LSSC     A0,12

```

```

      LDSC     A0,24
      LSSL     A1,6
      LXM,U    A1,050505
      DS       A0,*0,X11
      J        3,X11
      *
      *   A0=1= DD=MMH=YY##
      *   A0=1= DD=MMH=YY##
      *   A0=A1=DD=MMH=YY---
      *   GIVE IT TO THE USER
      *   RETURN
      *
      S(0)
      M
      *
      *   JAN
      *   FEB
      *   MAR
      *   APR
      *   MAY
      *   JUN
      *   JUL
      *   AUG
      *   SEP
      *   OCT
      *   NOV
      *   DEC
      *
      END
      *
      *   THIS SUBROUTINE WILL RETURN THE ELEVATION OF UTAH LAKE BASED UPON
      *   THE END OF MONTH CONTENT 'EOM'
      *
      *
      SUBROUTINE CAPUTL(EOM,CAPUTL,KX)
      COMMON AJST(7),QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
1ACOR(7),CAP(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
2IND(7,5),OTLV(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,10),
4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSRV(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON ACR, AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
SIPR,IUL,LYRO,CAP(1810),NUMENT,CAPG(1700),NUGNT,C(30,13,45)
1,NYR,INAF,
7VAR(41,12,7,13)
      IEOM=1.01+EOM + 1.0
      DO 314 J=IEOM,NUMENT
      KY=J
      IF((EOM + 12.0) .LE. CAP(J) ) GO TO 315
314  CONTINUE
      KX=NUMENT
      KY=NUMENT
      GO TO 316
315  IF(J.EQ.1) GO TO 3155
      KY = J
      KX = KY - 1
      GO TO 316
3155 KY = J
      KX=J
316  PKX=(EOM + 12.5 - CAP(KX) ) / ( CAP(KY) - CAP(KX) )
      CAPUTL = -13.35 + ((FLOAT(KX)) + PKX) * .01
      RETURN
      END
      *
      *   THIS SUBROUTINE WILL RETURN THE ELEVATION OF GOSHEN BAY BASED
      *   UPON THE END OF MONTH CONTENT OF 'EOM'
      *
      *
      SUBROUTINE CAPG00(EOM,CAPG00,KKX)
      COMMON AJST(7),QCOR(41,7,12),TMP1(7),VAR3(7),VAR4(7),
1ACOR(7),CAP(7),CCR(12),CONV(7,13),CPH(12),CWS(12),DLH(12),
2IND(7,5),OTLV(19),OTLV(4),PR(7,15),QDSIR(7,12),RSIM(7,7),ROTL(7),
3RPR(7,10),RVAR(41,12,7,2),SBNM(7,2),SDSIR(7,12),SIM(7,10),
4SYIC(7,6),TACR(7),TAPH(7),WCR(7,12),WPH(7,12),FMT1(4),FMT2(4),
5FMT3(4),FMT4(4),QSRV(7),QGRY(7),SAVA(7,2),PRLS(7),TSAVA(2)
6,CWT(7,2,5),AFMT1(4),AFMT2(4),AFMT3(4),AFMT4(4)
      COMMON ACR, AJSO,APH,CAJS,DIC,DIN,DOUT,IN1,IN2,IOUT,LYR,
1MEIR,MNTH,MSIR,NARA,NIND,NITX,NPR,NRPR,NRSM,NRVR,NSIC,NSB,NSM,NVR,
2SAJS,SK,BCF,BCK,ITOP,DAJS,ISOS,TAJS,DVAR(12),DRVAR(12),ADMS,
SIPR,IUL,LYRO,CAP(1810),NUMENT,CAPG(1700),NUGNT,C(30,13,45)
1,NYR,INAF,
7VAR(41,12,7,13)

```

```

      IEOM=EOM*4.5 + 1.0
      DO 414 J=IEOM,NUGNT
      KY=J
      IF ( EOM .LE. CAPG(J) ) GO TO 415
414  CONTINUE
      KX=NUGNT
      KY=NUGNT
      GO TO 416
415  IF(J.EQ.1) GO TO 4155
      KY = J

```

```

      KX = KY-1
      GO TO 416
4155 KY = J
      KX = J
416  PKX = ( EOM - CAPG(KX) ) / (CAPG(KY) - CAPG(KX) )
      CAPGOS = -13.15 + ((FLOAT(KX)) + PKX ) * .01
      KXX=KX
      RETURN
      END

```



# APPENDIX E

## EVAPORATION FROM UTAH LAKE

### Simulation of Evaporation From a Shallow Lake

by

Bi-Huei Wang  
J. Paul Riley

#### Introduction

In an attempt to simulate the hydrologic process of the Utah Lake basin in central Utah, it was noted that the evaporation from an open water surface plays an important role in the total hydrology of the area. The outflow from the basin is regulated by a large lake at its outlet. Because of the moderate water yield of the basin and the large area of the lake, a small change in the depth of evaporation from the lake causes a large change in the outflow from the lake. This sensitivity of the total hydrology to evaporation clearly indicates that, in simulating the hydrology of an area of this nature, a small error in estimating evaporation from open water surface may result in considerable departure of the simulated hydrology from its actual magnitude. The need for an adequate method to estimate the evaporation is, therefore, rather obvious and, in fact, motivated the present study.

There are numerous empirical and theoretical methods available for estimating evaporation from open water surfaces. Since Dalton (1802) first recognized that the rate of evaporation is proportional to deficit in vapor pressure, there have been many evaporation equations proposed on this basis. Some important ones are those proposed by Dalton (1802), Meyer (1915), and Harbeck (1954, 1958, 1962). Blaney and Criddle (1950) proposed a procedure using temperature and duration of possible sunshine. Jensen and Haise (1963), based on measured evapotranspiration and estimates of solar radiation for the periods involved, calculated the ratios of evapotranspiration to solar radiation and correlated the ratio to mean air temperature. Practicing engineers often estimate lake evaporation by applying a coefficient to pan evaporation. All of these methods have been meaningfully applied to particular areas, but are not applicable for locations where the empirical coefficients are not available.

The theoretical approach to the evaporation problem includes applications of mass-transfer theory and

energy balance analysis. By applying the mass-transfer theory, Thornthwaite and Holzman (see Linsley, Kohler, and Paulhus, 1958, page 97) were able to arrive at the following equation:

$$E = \frac{833k^2 (e_1 - e_2) (u_2 - u_1)}{(T + 459.9) \ln(z_2/z_1)^2} \dots (E-1)$$

in which

- E = rate of evaporation in inches per hour
- k = von Karman's constant
- e = vapor pressure in inches of mercury
- u = wind speed in miles per hour
- T = mean air temperature in °F
- z<sub>1</sub> = lower level
- z<sub>2</sub> = upper level

The energy budget approach to the problem leads to the following equation:

$$E = \frac{Q_s - Q_r - Q_b + Q_v - Q_\theta}{\rho L_e (1 + R)} \dots (E-2)$$

in which

- E = rate of evaporation
- ρ = density of water
- Q = rate of the energy components associated with the evaporation process
- L<sub>e</sub> = latent heat of vaporization
- R = Bowen ratio

Penman (1948), through simultaneous solution of an empirical mass-transfer equation and the energy budget equation, derived the following equation:

$$E = \frac{1}{\Delta + \gamma} (Q_n \Delta + \gamma E_a) \dots (E-3)$$

in which

- Δ = slope of the saturation-vapor-pressure

vs. temperature curve at the air temperature,  $T_a$

$E_a$  = evaporation rate given by an empirical mass-transfer equation, assuming the water temperature  $T_s = T_a$

$Q_n$  = net energy exchange expressed in the same unit as evaporation  $E$ .

$\gamma$  = is defined by the Bowen ratio equation

$$R = \gamma \frac{T_s - T_a}{e_s - e_a} \dots \dots \dots (E-4)$$

in which

$e_s$  = saturation vapor pressure corresponding to  $T_s$

$e_a$  = vapor pressure of the air at  $T_a$

Each of the theoretical equations described above has a sound theoretical basis and, therefore, is expected to have a more general applicability to the evaporation problem. However, the Thornthwaite-Holzman equation needs vapor pressure and wind speed data at two levels which are usually not available and the energy budget and Penman equations contain empirical functions which limit the applicability of the equations.

Van Bavel (1966) improved the Penman equations by eliminating the requirement for the empirical function. He tested the resulting equation with the experimental data in Phoenix, Arizona, and claimed an excellent agreement between the calculated and measured values on both an hourly and a daily basis. The present study follows essentially the same method but incorporates an equation describing the variation of reservoir water temperature, and thereby provides for an improved estimation of energy and water exchange between the water surface and the over-lying air.

### Mathematical Model

As was mentioned in the previous section, there are two fundamental approaches to the theoretical study of evaporation from open water surfaces. One involves application of mass-transfer theory and the other involves keeping an energy budget.

Assuming a steady, uniform flow of air across a free-water surface of infinite extent and a logarithmic distribution of wind speed, the following equation can be derived by considering the vertical flux of water vapor and momentum,

$$E_o = \frac{\rho \epsilon}{p c_1^2} \frac{(u_2 - u_1)(e_1 - e_2)}{\ln^2(z_2/z_1)} \dots (E-5)$$

in which

$E_o$  = rate of evaporation in  $g \text{ cm}^{-2} \text{ sec}^{-1}$

$c_1$  = a dimensionless constant in the wind velocity distribution equation

$e$  = vapor pressure in the same unit as  $p$

$p$  = total pressure in the same unit as  $e$

$u$  = wind velocity in  $\text{cm sec}^{-1}$

$\rho$  = density of moist air in  $g \text{ cm}^{-3}$

$\epsilon$  = ratio of the densities of water vapor and dry air at the same temperature and pressure ( $\approx 0.622$ )

$z$  = height above the water surface; and the larger subscript indicates the higher elevation

From an energy balance consideration, the following equation can be obtained

$$E = \frac{I_s - I_r - I_b + I_v - I_\theta}{\rho_e L_e (1 + R) A} \dots \dots (E-6)$$

in which

$E$  = evaporation rate in  $\text{cm sec}^{-1}$

$A$  = water surface area in  $\text{cm}^2$

$I_s$  = rate of incoming sun and sky short-wave radiation in  $\text{cal sec}^{-1}$

$I_r$  = rate of reflected short-wave radiation in  $\text{cal sec}^{-1}$

$I_b$  = rate of net outgoing long wave radiation in  $\text{cal sec}^{-1}$

$I_v$  = rate of energy advected into the water body in  $\text{cal sec}^{-1}$

$I_\theta$  = rate of increase in energy storage in  $\text{cal sec}^{-1}$

$L_e$  = latent heat of vaporization in  $\text{cal g}^{-1}$

$\rho_e$  = density of evaporated water in  $g \text{ cm}^{-3}$

$R$  = the Bowen ratio

Combining Equations E-5 and E-6 by using the following relationship,

$$I_e = L_e E_o A \dots \dots \dots (E-7)$$

in which

$I_e$  = rate of energy used for evaporation in  $\text{cal sec}^{-1}$ , and by letting  $I_R = I_s - I_r - I_b - I_\theta + I_v$ , the following equations are formed:

$$E = \frac{1}{\rho_e L_e} \frac{(\Delta/\gamma) I_R/A + L_e B e_d}{(\Delta/\gamma) + 1} \dots (E-8)$$

$$B = \frac{\rho \epsilon}{p c_1^2} \frac{u_2^2}{\ln^2(z_2/z_o)}$$

in which

$e_d$  = saturation vapor deficit at height  $z_2$

$z_o$  = surface roughness parameter as defined by Van Bavel (1960) and the other terms are as previously defined

The application of Equation E-8 requires temperature at the water surface in order to evaluate some of the component energy terms included in  $I_R$ . Water surface temperature data are usually not available. However, for shallow reservoirs, considering the stirring action by wind

and inflowing streams, it seems reasonable to assume that the temperature distribution is fairly uniform. On the basis of this assumption, the variation of water temperature with respect to time can be expressed as

$$\frac{dT_s}{dt} = \frac{I_\theta}{c \rho_w V} \dots \dots \dots (E-9)$$

in which

- $T_s$  = water temperature in degrees C
- $c$  = specific heat of the water in cal g<sup>-1</sup> °C<sup>-1</sup>
- $V$  = volume of the reservoir storage in cm<sup>3</sup>
- $t$  = time in sec
- $\rho_w$  = density of the water in g cm<sup>-3</sup>
- Let  $I_t = I_s - I_r - I_b - I_h - I_e$

$$\text{then } I_\theta = I_s - I_r - I_b - I_h - I_e + I_v = I_t + I_v \dots (E-10)$$

Assuming that the temperature of the outflow from the reservoir is essentially the same as that of the reservoir storage and that the temperature of the precipitation can be approximated by the wet-bulb temperature, the rate of net advected energy,  $I_v$ , can be estimated by

$$I_v = c \rho_w \left[ \sum_{i=1}^n Q_i (T_i - T_s) + P_r A (T_w - T_s) \right] \dots \dots (E-11)$$

in which

- $n$  = number of inflowing surface and underground tributaries
- $Q_i$  = rate of tributary inflow in cm<sup>3</sup> sec<sup>-1</sup>
- $T_i$  = temperature of the inflowing water in °C
- $T_w$  = wet-bulb temperature in °C
- $P_r$  = precipitation rate in cm sec<sup>-1</sup>

Substituting Equation E-10 and E-11 into Equation E-9,

$$\frac{dT_s}{dt} = \frac{I_t + c \rho_w \left[ \sum_{i=1}^n Q_i (T_i - T_s) + P_r A (T_w - T_s) \right]}{c \rho_w V} \dots (E-12)$$

The evaporation rate,  $E$ , then can be obtained by solving Equations E-8 and E-12 simultaneously. The advantages of the proposed method over the existing methods are that it requires no empirical coefficient or function and needs only measurements at a single level,  $z_2$ . The method also simulates water temperature in the reservoir which allows an improved estimation of long wave radiation and net advected energy in Equation E-8, and at the same time provides another check on the validity of the model.

## Application

In applying the proposed method, careful determination of the energy components in Equation E-8 is important. To estimate the short-wave radiation received on the water surface,  $I_s$ , it is essential to have actual measurements. The Weather Bureau has collected solar radiation measurements at various locations throughout the United States. Of the total amount of short-wave radiation that reaches the water surface, a portion,  $I_r$ , is returned to the air by reflection. The reflectivity of a plane water surface is a function of the angle of incidence of the energy and the index of refraction of the water (see List, 1968, page 444) and may be computed from the reflection law of Fresnel,

$$r = \frac{1}{2} \left[ \frac{\sin^2 (\theta_i - \theta_r) + \tan^2 (\theta_i - \theta_r)}{\sin^2 (\theta_i + \theta_r) + \tan^2 (\theta_i + \theta_r)} \right] \dots (E-13)$$

in which

- $r$  = reflectivity of the water surface
- $\theta_i$  = angle of incidence =  $\sin^{-1} (\sin \phi \sin \delta + \cos \phi \cos \delta \cos h)$
- $\theta_r$  = angle of refraction
- $\phi$  = latitude of the site
- $\delta$  = declination of the sun
- $h$  = hour angle of the sun
- $\theta_i$  and  $\theta_r$  are related to the index of refraction,  $n$ , of water by

$$n = \sin \theta_i / \sin \theta_r \dots \dots \dots (E-14)$$

in which

- $n$  = 1.333 for pure water

Net back radiation,  $I_b$ , is defined as the difference between the long wave radiation leaving the water surface and the long wave radiation absorbed by the water surface. Raphael (1962) suggested that it can be estimated by

$$I_b = 0.970 \sigma (T_{sa}^4 - \beta T_a^4) A \dots (E-15)$$

in which

- $T_a$  = absolute temperature of the air in °K
- $T_{sa}$  = absolute temperature of the water in °K
- $\beta$  = a radiation factor as shown by Figure E-1
- $\sigma$  = Stefan-Boltzman constant,  $8.132 \times 10^{-11}$  cal cm<sup>-2</sup> min<sup>-1</sup> °K<sup>-4</sup>

$\Delta/\gamma$  in Equation E-8 is a dimensionless constant depending on the ambient temperature and pressure shown in Table E-1 and Equation E-16

$$\frac{\Delta}{\gamma} = \frac{1,000}{p} \left( \frac{\Delta}{\gamma} \right)_o \dots \dots \dots (E-16)$$

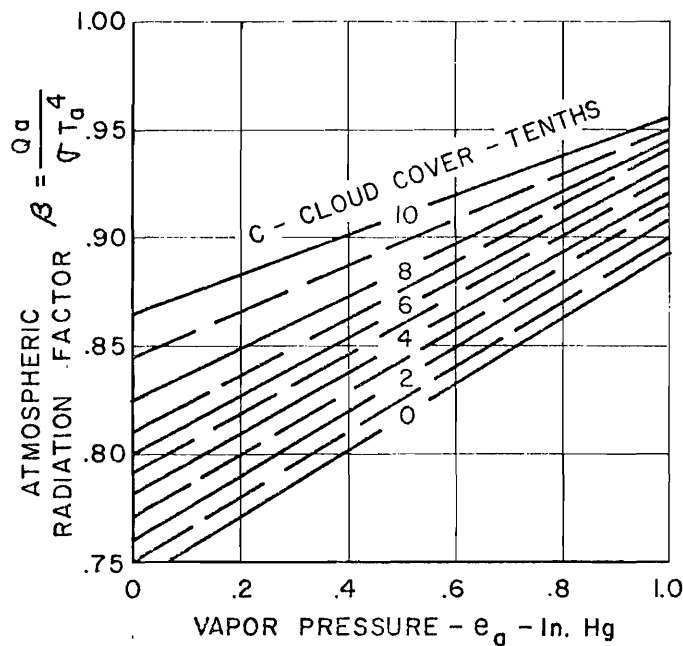


Figure E-1. Atmospheric radiation factor,  $\beta$  (see Raphael, 1962).

in which

$p$  = ambient pressure in m bar; and  $(\Delta/\gamma)$   
= value in Table 1

With Equation E-13 through E-16 and Table E-1 available at hand, the mathematical model, Equations E-8 and E-12, was programmed on the EAI 590 computer and incorporated in the hydrologic model for the Utah Lake in Central Utah. The hydrologic model was constructed so as to have lake storage and water temperature as outputs for comparison with the corresponding observed data. The model was operated on a daily basis for the period from October 1965 to September 1968. Reliable solar radiation, wind speed, temperature, precipitation and stream-flow records are available for that period. The validity of the model was tested by comparing the simulated and the observed lake storage (see Figure E-2b for the period October 1965 to September 1968). The limited water temperature records were also used to check the variation pattern of the simulated temperature as shown in Figure E-3. Some temperatures observed in the summers were not plotted in the figure because they were observed nearly at the water surface and believed to be greatly affected by the high temperature of the over-lying air and, therefore, not representative of the average temperature simulated. Water temperatures were not observed during the winter months. However, if measurements were made

Table E-1. Values of  $(\Delta/\gamma)_0$  at 1,000 mbar, temperature T°C.

T	$(\Delta/\gamma)_0$	T	$(\Delta/\gamma)_0$	T	$(\Delta/\gamma)_0$	T	$(\Delta/\gamma)_0$	T	$(\Delta/\gamma)_0$	T	$(\Delta/\gamma)_0$
0.0	0.67	10.0	1.23	20.0	2.14	30.0	3.57	40.0	5.70	50.0	8.77
0.5	0.69	10.5	1.27	20.5	2.20	30.5	3.66	40.5	5.83	50.5	8.96
1.0	0.72	11.0	1.30	21.0	2.26	31.0	3.75	41.0	5.96	51.0	9.14
1.5	0.74	11.5	1.34	21.5	2.32	31.5	3.84	41.5	6.09	51.5	9.33
2.0	0.76	12.0	1.38	22.0	2.38	32.0	3.93	42.0	6.23	52.0	9.52
2.5	0.79	12.5	1.42	22.5	2.45	32.5	4.03	42.5	6.37	52.5	9.72
3.0	0.81	13.0	1.46	23.0	2.51	33.0	4.12	43.0	6.51	53.0	9.92
3.5	0.84	13.5	1.50	23.5	2.58	33.5	4.22	43.5	6.65	53.5	10.1
4.0	0.86	14.0	1.55	24.0	2.64	34.0	4.32	44.0	6.80	54.0	10.3
4.5	0.89	14.5	1.59	24.5	2.71	34.5	4.43	44.5	6.95	54.5	10.5
5.0	0.92	15.0	1.64	25.0	2.78	35.0	4.53	45.0	7.10	55.0	10.8
5.5	0.94	15.5	1.68	25.5	2.85	35.5	4.64	45.5	7.26	55.5	11.0
6.0	0.97	16.0	1.73	26.0	2.92	36.0	4.75	46.0	7.41	56.0	11.2
6.5	1.00	16.5	1.78	26.5	3.00	36.5	4.86	46.5	7.57	56.5	11.4
7.0	1.03	17.0	1.82	27.0	3.08	37.0	4.97	47.0	7.73	57.0	11.6
7.5	1.06	17.5	1.88	27.5	3.15	37.5	5.00	47.5	7.90	57.5	11.9
8.0	1.10	18.0	1.93	28.0	3.23	38.0	5.20	48.0	8.07	58.0	12.1
8.5	1.13	18.5	1.98	28.5	3.31	38.5	5.32	48.5	8.24	58.5	12.3
9.0	1.16	19.0	2.03	29.0	3.40	39.0	5.45	49.0	8.42	59.0	12.6
9.5	1.20	19.5	2.09	29.5	3.48	39.5	5.57	49.5	8.60	59.5	12.8
10.0	1.23	20.0	2.14	30.0	3.57	40.0	5.70	50.0	8.77	60.0	13.1

(From Van Bavel, C.H.M.: Potential Evaporation: The Combination Concept and Its Experimental Verification, Water Resources Res., Vol., no. 3, pp. 455-67, 1966)

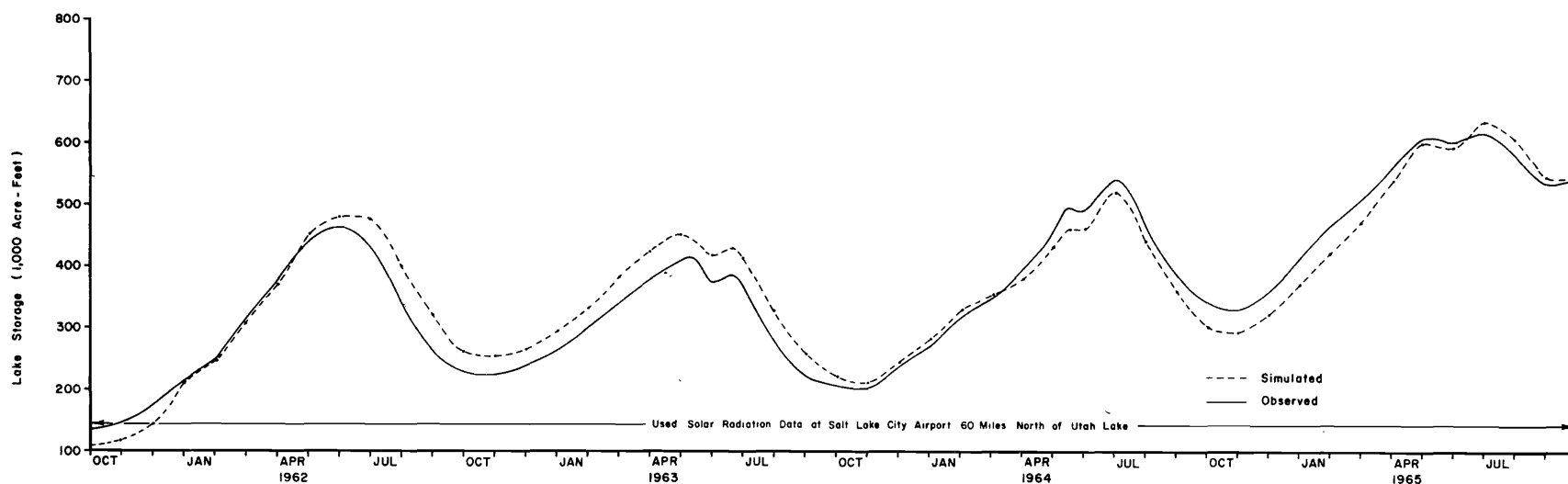


Figure E-2a. The comparison of simulated and observed lake storage, Utah Lake.

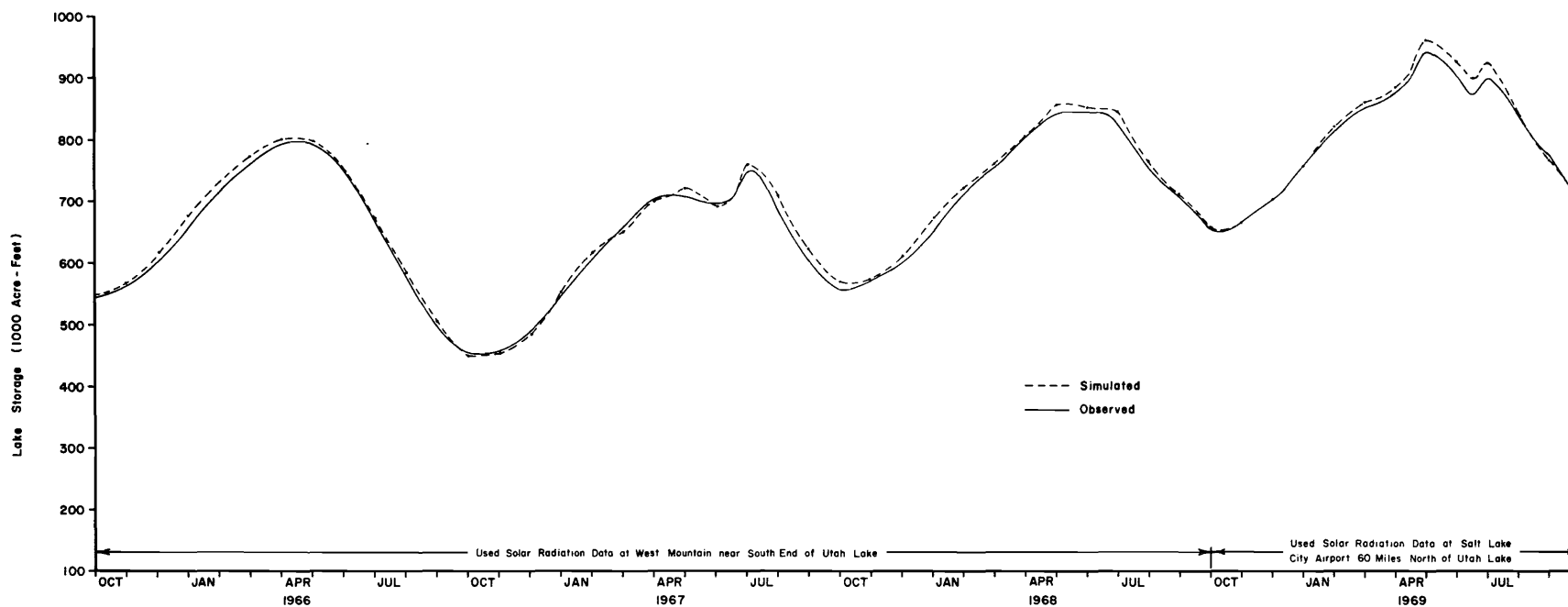


Figure E-2b. The comparison of simulated and observed lake storage, Utah Lake.



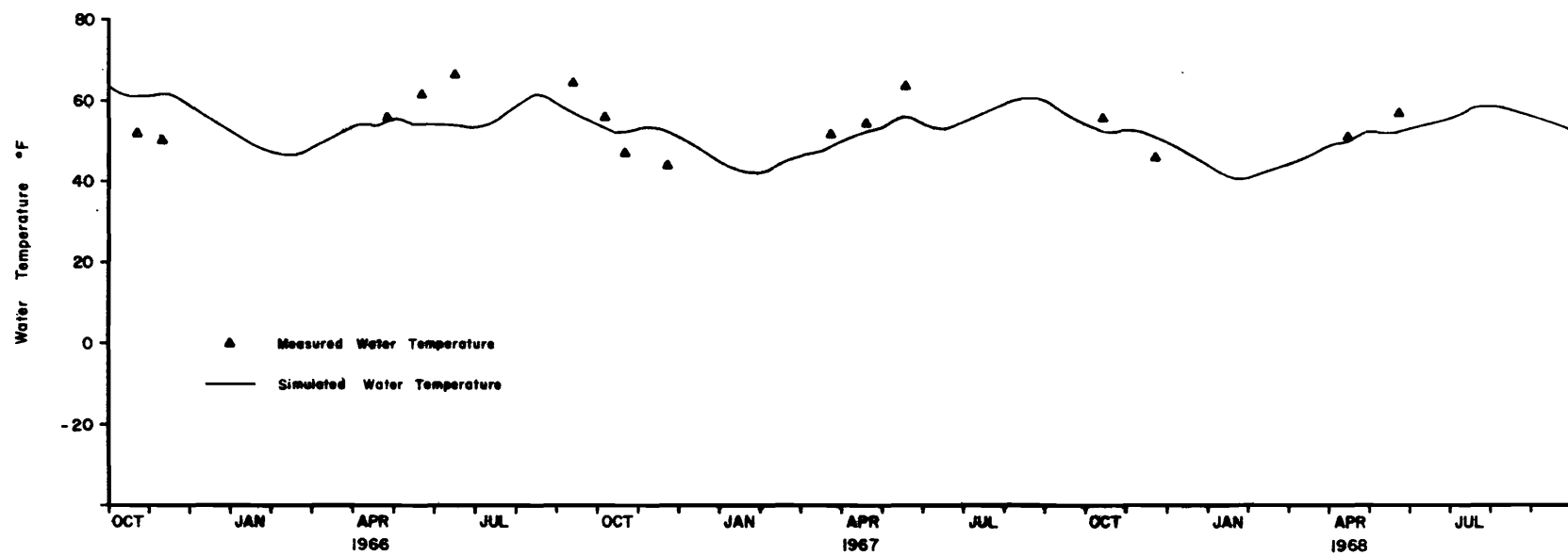


Figure E-3. The comparison of simulated and observed water temperature, Utah Lake.

at the water surface, it is believed that they would plot mostly below the simulated water temperature because of the influence of the cold over-lying air.

The excellent agreement between the simulated and observed storage hydrographs, and the reasonable agreement between the simulated and observed water temperatures indicate the adequacy of the model in simulating evaporation from the lake.

Unfortunately, for many areas, the amount of available solar radiation data is limited. To extend the application of the proposed model to periods for which no such data are available, the following procedure was adopted:

1. Operate the model for the period in which solar radiation and the other necessary data are available.
2. Assume that the simulated evaporation estimates accurately the actual evaporation, and correlate this simulated evaporation to readily available data such as pan evaporation.
3. Apply the resulting regression equation to estimate evaporation for periods in which the proposed model, Equations E-8 and E-12, is not directly applicable.

For the area under consideration in this study, there were three years of sufficient data available for operating the model. An additional five years of data were made available by approximating the local insolation with measurements at Salt Lake City Airport which is located 40 miles to the north. Figures E-2a and E-2b indicate the simulation results for the additional five-year period in terms of the lake storage hydrograph. The observed storage variation for the corresponding period is also shown by the same figure. These results were considered to be acceptable and the simulated evaporation was, therefore, assumed to approximate the actual evaporation. Monthly simulated evaporation data were then correlated to corresponding pan evaporation data. Pan evaporation measurements have been made at Lehi near the lake since 1923. Figure E-4 shows that relationship between the simulated lake evaporation and the observed pan evaporation. It is interesting to note that on the basis of this

relationship, the conventional constant "pan coefficient" method of estimating lake evaporation tends to underestimate actual evaporation in the winter and overestimate it in the summer.

## Discussion

The model described by this paper satisfactorily simulated evaporation from an open water surface. The model requires no highly empirical functions or coefficients and is easily incorporated in any hydrologic simulation model. However, in the operation of the model, it was necessary to set maximum limits on the rate of water temperature change and on the rate of evaporation. Without these limitations, the simulated water temperature and evaporation performs wild variations which are not physically realistic. This is probably due to the assumption that the water temperature distribution is uniform throughout the entire lake. The thermal conductivity of water may limit immediate conduction of heat from surface to bottom or from bottom to surface, and thus, limits the maximum rate of change in average water temperature. Similar conditions may exist in the water vapor transfer between the water surface and the over-lying air. The maximum limits established by the model for the rate of temperature change and evaporation serve to make some compensation for the possible errors introduced by the assumption of uniform water temperature distribution. The maximum limits were identified through the model calibration procedure.

The lake and pan evaporation relationship shown in Figure E-4 is interesting in that it differs from the general assumption of linear relationship between the two variables. As mentioned at the beginning of this paper, it has long been the practice among many engineers to estimate lake evaporation by applying a constant coefficient to the corresponding pan evaporation. However, during winter months, water temperatures in a large lake may be higher than those in a nearby evaporation pan, and a higher than annual average ratio between lake and pan evaporation amounts is expected. In summer, the condition reverses, and a smaller coefficient is, therefore, expected. The relationship in Figure E-4 reflects this expected variation of pan coefficient with respect to season.

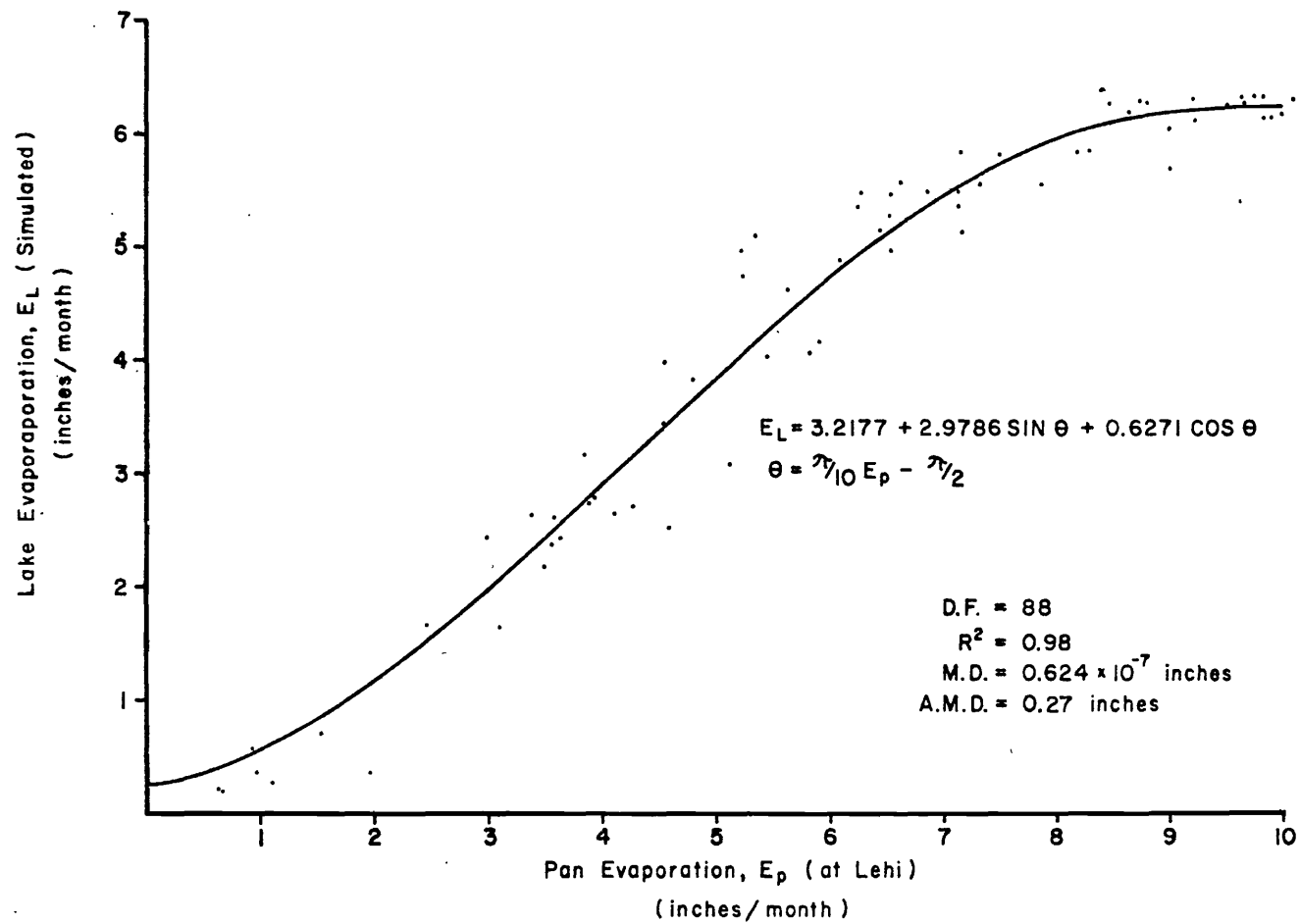


Figure E-4. Lake and Pan Evaporation Relationship, Utah Lake